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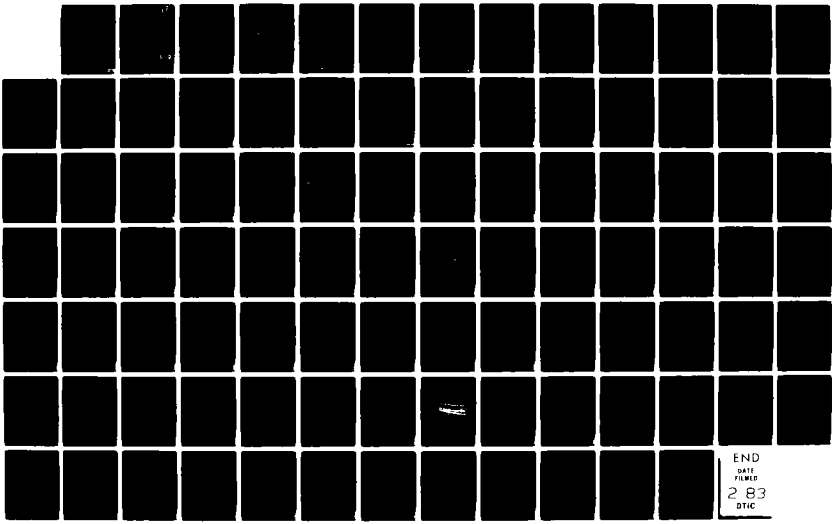

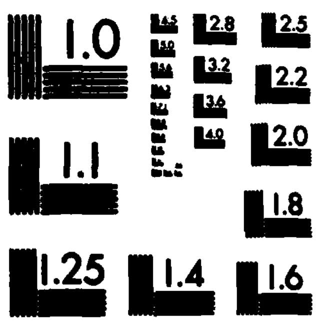

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Noise Pollution Aspects of Barge, Railroad,

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by

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April 1975

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Transportation noises are the major source of noise in urban environs, accounting for three-fourths of the noise level urban dwellers experience. Barge generated noises do not rank as intrusive as that of trains and heavy trucks, some reasons include: barges are less numerous; barges are slower and do not generate high db levels from interation with water surface as trucks or trains produce in interaction with pavement or steel tracks; the barge channel is often 450 feet from shore; and rivers tend to have natural sound barriers such as bluffs and riparian vegetation.

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Noise Pollution Aspects of Barge, Railroad and Truck Transportation

I. Characteristics & Physical Measurement of Sound

A. General

Sound consists of three major components: (1) intensity, (2) frequency and (3) duration. Sound becomes noise when any one or more of the above components become excessive. Excessiveness, however, is a subjective judgment which complicates the measurement of sound as perceived by the individual.

B. Calculation of Sound Intensity

Intensity of the physical measurement of a given sound is determined by measuring the pressure generated in the atmosphere by a source radiating sound. The difference in pressure generated by a source compared to a base or reference sound pressure indicates the intensity or the sound pressure level. The dimensionless units used in measuring the sound pressure level (SPL) are called decibels and the formula which enables determination of the number of decibels (dB) a particular sound produces is:

$SPL = 20 \log_{10} \frac{P}{P}$ dB, where

SPL is the sound pressure level of a measured sound in decibel (dB)

dB (decibels) express the logarithmicratio of a measured sound pressure (P) to a reference (base) sound pressure

P_o is the reference pressure considered to be the weakest audible pressure a normal ear can detect under ideal listening conditions (0.0002) microbars).

P_o is assigned an intensity of zero dB in the establishment of the decibel scale. The more intense sound levels, consequently, will produce higher dB levels. The logarithmic component is used in calculating SPL means that the geometric increase in sound pressure can be represented by an arithmetical increase in the dB scale. For every 10dB increase in scale, the pressure produced by a given sound level will more than triple (see Table 1).

Because the decibel (dB) is a logarithm of a ration of two values, it can also describe sound energy. Sound energy equivalents are shown in Table 2. The data in Table 2 reveals that with every arithmetical increase in dB, the relative change in sound energy increases geometrically 10 times. For example, an increase in intensity of sound level from 60dB to 80dB means that a corresponding change in sound energy of 100 times (from 1,000,000 to 100,000,000) will occur.

C. Calculation of Sound Intensity from Multiple Sources

The intensity of multiple noise source can be calculated, but some confusion can result without the following explanation. Consider two barges, one of which generates 90dB and the other 88dB. The noise level generated by the two barges together is 92.1dB and not 178dB (90+88). The energy level produced by the two barges is almost doubled, but numbers of dB are never directly added. First, dB levels are converted to relative powers (the logarithmic ratio expression), added (or subtracted), and then converted back to dB. The calculation of multiple noise intensities is made easily and swiftly from the chart shown in Figure 1. As an example, locate 2dB on the "Numerical Difference between Two Levels Being Added" scale, then read directly across to the left hand vertical scale and read 2.1dB. Add 2.1dB to the larger of the noise sources (90dB + 2.1dB = 92.1dB) to arrive at the aggregate noise level for the two barges.

Table 1. Noise Levels Measured in Microbars

Sound pressure (microbars)	*Sound pressure level (dB re 0.0002 microbar)*	*Noise source*
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	
0.0063	30	
0.02	40	
0.063	50	
0.2	60	Conversation
0.63	70	
1.0	74	Vacuum cleaner
2.0	80	
6.3	90	Subway
20	100	Snowmobile
63	110	Air hammer
200	120	Chain saw
2000	140	22 caliber rifle

Source: C.R. Bragdon, Noise Pollution (University of Pennsylvania Press, 1970), p. 52.

Table 2. Noise Levels Measured in Sound Energy

Relative change in sound energy	*Decibels*	*Noise source*
1	0	Threshold of hearing
1,000	30	Whispering
1,000,000	60	Conversation
100,000,000	80	Food blender
10,000,000,000	100	Heavy traffic
1,000,000,000,000	120	Jet aircraft

Source: C.R. Bragdon, Noise Pollution (University of Pennsylvania Press, 1970), p. 52.

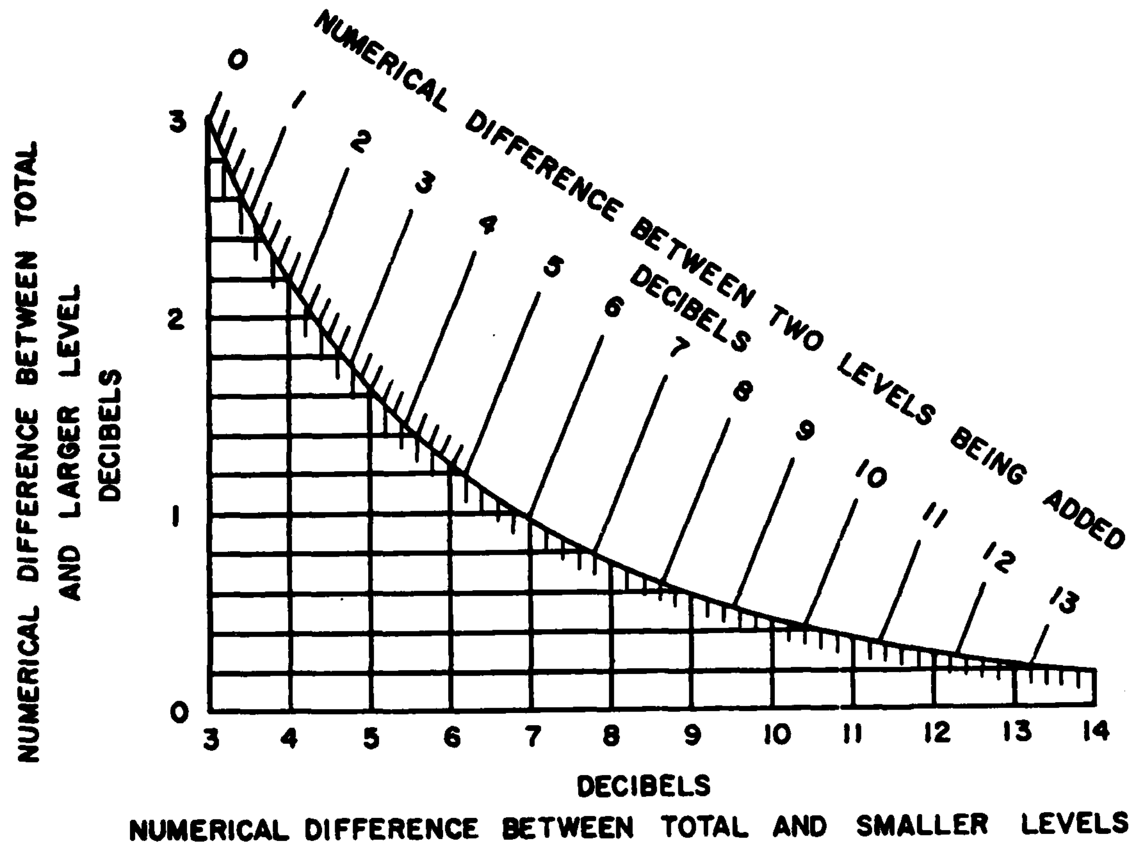


FIGURE 1. *Chart for combining levels of uncorrelated noise signals.* Source: *A. Peterson and E. Gross, eds.,* Handbook of Noise Control *(West Concord: General Radio Company, 1967).*

D. Frequency and its role in Noise

Frequency, as the second component of sound, describes the number of times a complete cycle occurs in one second and is measured in a unit designated as Hertz (Hz). In measuring sound to ascertain its impact, a frequency analysis is normally accomplished to determine the way in which noise intensity is distributed throughout the range of Hz the human ear is capable of detecting. In a frequency analysis, eight bands are utilized with each band designated as an octave and subsequently a sound pressure level (in dB) is obtained for each octave. The eight conventional octaves are centered around eight preferred frequencies for purposes of acoustical measurements (63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz).

Two noises having similar overall sound pressure levels can display completely different frequency distributions. A comparison of the frequency distribution of a propeller and jet aircraft emit the most noise in frequencies of 150 - 600 Hz (see Figure 2). Even though the noise intensity produced by the propeller aircraft is slightly more than the jet, it is less irritating to the human ear because the frequencies of maximum noise output by the propeller aircraft are lower than that of the jet aircraft.

In subsequent sections, references will be made to sound levels in dB followed by another letter A, B, or C. These letters are associated with specific frequency curves of standard sound level meters that selectively discriminate against low and high frequencies (see Figure 3). Each letter depicts a specific "weighing network". The A & B networks progressively alternate or suppress frequencies less than 1000 Hz. Of the three scales, the A-scale is the most preferred weighing network, because it most closely

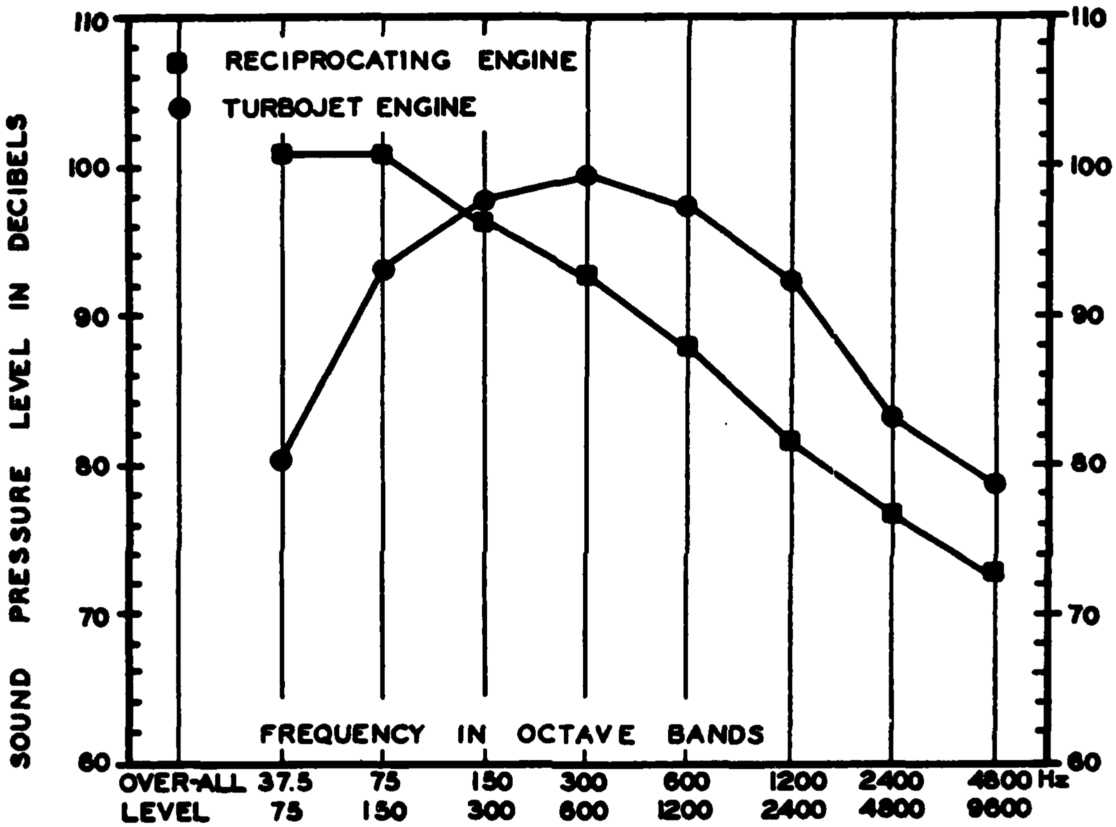


FIGURE 2 *Frequency distribution of aircraft noise measured in cockpit. Data from Major Donald Gasaway, "Aeromedical significance of noise exposures associated with the operation of fixed- and rotary-winged aircraft" (USAF School of Aerospace Medicine, Brooks AFB, Texas, November, 1965, mimeographed).*

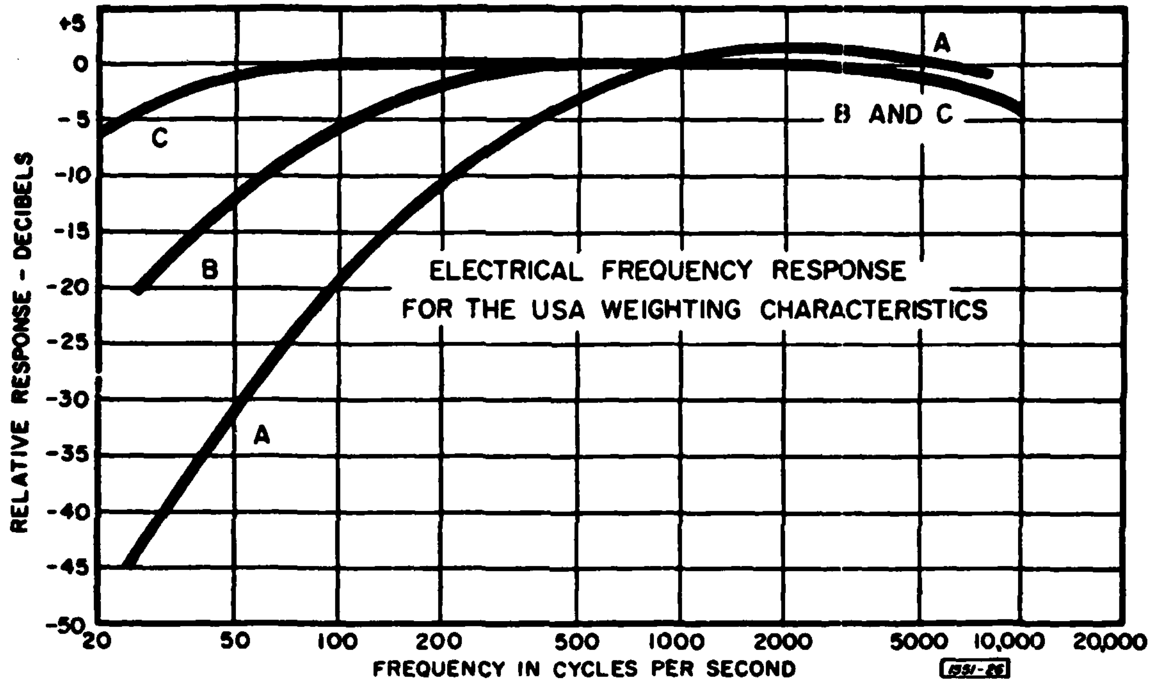


FIGURE 3. *Frequency response characteristics in the ANSI standard for sound level meters.* Source: *A. Peterson and E. Gross,* Handbook of Noise Control *(West Concord: General Radio Company, 1967).*

simulates the way the human ear perceives sound. When reference is made to the A-weighted network, it is indicates as dB(A) or the A-weighted sound sound level in dB.

E. Duration of Sound and Its Role in Producing Noise

Duration of sound or noise is the third component of sound to be considered because hearing loss in the case of the human ear is directly affected by duration of exposure. The curve resembling a classic exponential decay curve in Figure 4 represents the recommended maximum noise exposures as a function of time. Under this scheme, an individual can be exposed to a sound level of 105dB(A) for 60 minutes or 30 minutes to a sound level of 110 dB(A).

The threshold values of intensity combined with time exposure as shown in Figure 4 are the basis for the occupational noise provisions of the Occupational Safety and Health Act. When exposure to noise is intermittent rather than continuous, the individual concerned can tolerate either higher intensities or the same intensity levels for longer periods.

Duration, in addition, should be considered when evaluating subjective responses to noise. The perceiver will generally tolerate a noise occurring with consistent regularity (provided it is not intense). Random, intermittent noise, however, of the same intensity will not be tolerated as readily by the perceiver.[1] Noises produced by railroads and barges are random, sporadic sources in contrast to highway noises and will provoke a more negative response than the more patterned consistent highway noise sources.

[1] p. 58, C. R. Bragdon, Noise Pollution

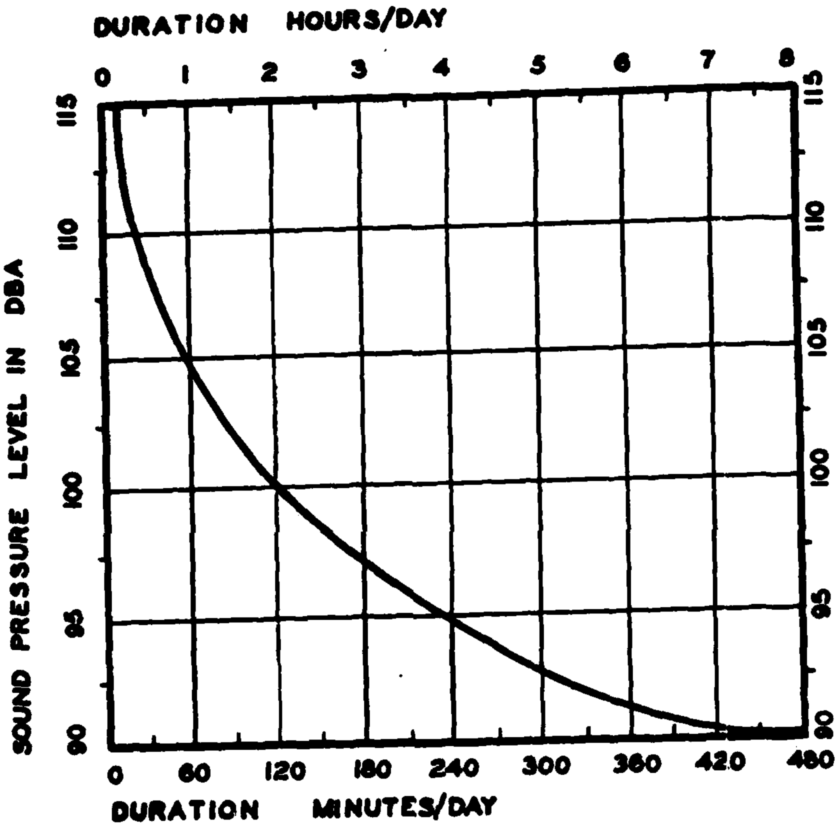


FIGURE 4. *Maximum recommended noise exposure in dBA for 8 hours or less. Data from Second Intersociety Committee on Guidelines for Noise Exposure*, Guidelines for Noise Exposure, *October 24, 1969.*

II. Attenuation of Noise

A. General

1. Much of the literature concerning attenuation of sound in the open air is of a theoretical nature. One of the main reasons for this is the fact that propogation of sound in open air is highly dependent on frequency and a number of environmental factors such as temperature and wind structures, humidity, vegetative cover and terrain features. All of these factors are dynamic or highly localized making it difficult to produce a general mathematical predictive model as well as acquiring the observations and data required for such a model.

2. The Federal Highway Administration (FHWA) presently approves two prediction models for noise levels in order to apply noise standards for locations at varying distances from a highway.[1] The noise prediction method contained in the National Cooperative Highway Research Program Report 117 and the method contained in DOT Transportation Systems Center Report DOT-TSC-FHWA-72-1 have been sanctioned by the FHWA since November, 1972 for noise levels generated by motor vehicles on urban streets and highways.

3. The FHWA models would be used for predicting noise levels of transportation models other than motor vehicles in environments differing from those of urban neighborhoods, but no model has been developed specifically for comparing noise levels generated by different modes of transportation under varying environmental conditions. This report, consequently, will project noise levels from alternative modes of transport on the basis of theoretical attenuations that should occur under a set of

[1]FHWA, Noise Standards and Procedures, Nov. 1972, NTIS (EIS-AA-72-5822-F), p. 170

specific environmental conditions. The projections are listed in Appendix 1.

B. Attenuation Factors

In order to determine sound levels at varying distances from a point (or line) source of sound, the following factors are determinant.

1. Geometric attenuation or a divergent decrease of sound energy according to the inverse square law. The following equations expresses the sound pressure level (Lp) in dB at distance Γ:

(a) $L_p = L_x - 20 \log_{10} \frac{\Gamma}{\Gamma} + 2.4\text{dB}$ where

L_x is a known sound pressure level in dB at distance Γ_x from a point source generating sound in a free field environment and 2.4 is a compensation factor from a ground level sound source which accounts for ground reflection.[1]

(b) for a line source of sound (a highway or a long freight train)

$L_p = L_x - 10 \log_{10} \frac{\Gamma}{\Gamma} + 2.4\text{dB}$

(c) the relationship describing the propagation of sound from a point source shows that as distance doubles, a decrease of 6dB is to be expected from geometric attenuation.

(d) the line source sound pressure level can be expected to be 3dB less with a doubling of distance.

[1] The discussion of propagation of sound in this section is based largely on Rudnick, Isadore, "Propagation of Sound in the Open Air", Handbook of Noise Control (ed. Harris, Cyril M.) McGraw-Hill Co., Inc., New York, 1957, pp. 3-1 to 3-17.

2. Atmospheric attenuation or the attenuation of sound in air due to certain physical properties of the atmosphere. The attenuation constant (α) is made up of two components:

(a) The first component (α_1) is unimportant except for very high frequencies and is relatively unaffected by relative humidity.

(b) The second component (α_2) is strongly dependent upon relative humidity and temperature.

(c) Total atmospheric attenuation (α) is given by:

$$\alpha=\alpha_1+\alpha_2 = 4.2x10^{-9}F^2+\alpha_2$$

where α_1 and α_2 are dB per 100 feet and F is frequency in Hz.

(d) The nomograph in Figure 5 shows the relation of α_2 values to different combinations of temperature and relative humidity levels.

(1) The graph shown in Figure 5 reveals that frequencies below 2000Hz are hardly attenuated by the α_2 component over a 100 foot distance.

(2) Frequencies of more than 2000Hz show some attenuation for distances of more than 400 feet, especially as relative humidities decrease and temperatures increase.

(3) Very little α_2 attenuation occurs in fog (100 percent relative humidity) at the frequency levels that barges, trucks and trains radiate most of their sound energy.

(e) Total atmospheric attenuation (α) is shown in Figure 6 at a temperature of 68°F and relative humidities of 20, 40, 60, and 80 percent. The α_1 component (the dashed line) is shown to be very slight until frequencies of more than 2,000 Hz are in effect.

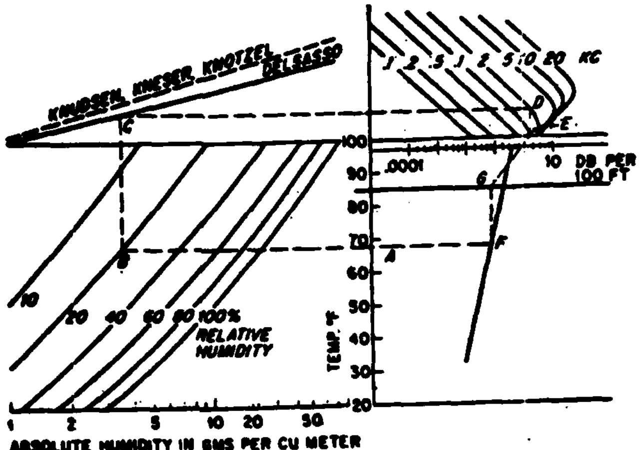


Fig. 5. Nomogram for obtaining the attenuation due to molecular vibration relaxation absorption coefficient α_3. Illustrated is an example in which the temperature is 68°F, the relative humidity is 20 per cent, and the frequency is 2.000 cps. The attenuation is then 0.9 db per 100 ft. The curve marked Kneser, Knudsen, and Knotzel is based on separate measurements by the latter two[2,3] and is recommended by Kneser. The curve marked Delsasso is based on recent measurements[4] which are close to those of Knudsen and Obert.[4] It is difficult to choose between these data, but the use of Delsasso's results is recommended.

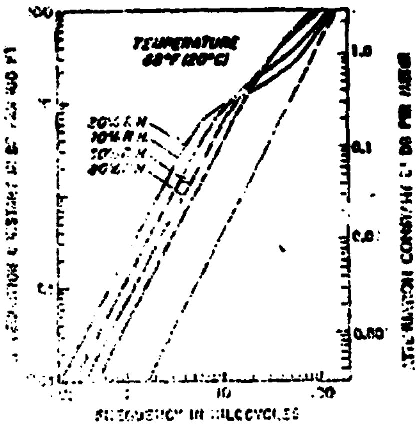


Fig. 6. The attenuation coefficient in decibels per meter for air at a temperature of 68°F [illegible] humidities of 20, 40, 80, and [illegible] per cent. The solid curves give the [illegible] attenuation coefficient; the dotted [illegible] the contribution to this total [illegible]

Source: C.M. Harris, ed., Handbook of Noise Control (McGraw-Hill Book Co., 1957) p. 3-3.

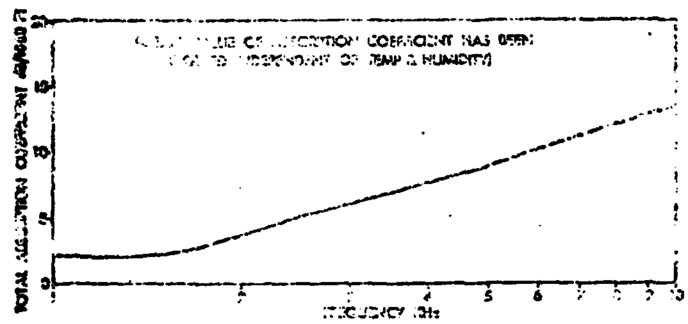


Fig. 7. Total atmospheric attenuation vs frequency.

Source: J.D. Chalupnik, ed., Transportation Noises (University of Washington Press, 1970) p. 5.

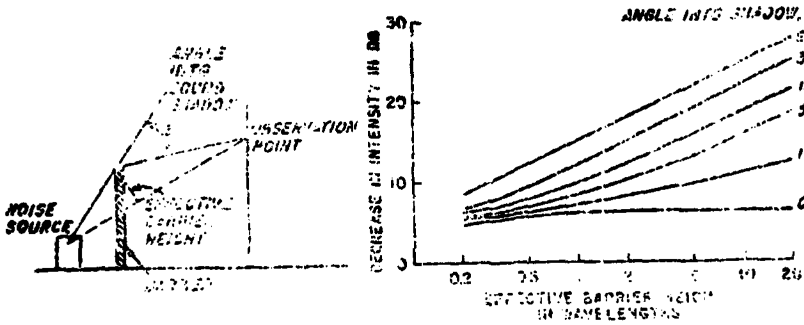


Fig. [illegible] Shielding provided by barriers.

Source: C.M. Harris, ed., Handbook of Noise Control (McGraw-Hill Book Co., 1957) p. 3-4.

(f) Total atmospheric attenuation as measured by British Aircraft Corporation is shown in Figure 7.[1] The relationship of noise attenuation is revealed to be much more dependent on frequency than on relative humidity and temperature values. It is also apparent from an examination of Figure 7 that at frequencies of 1000Hz or less, attenuation due to the atmosphere will be no more than 2dB over a 1000 foot distance.

(g) The inconsistencies between the British Aircraft Corporation findings and theoretical values as shown in Figures 5 and 6 can be partially explained by the fact that in the British study, relative humidity was never less than 50 percent and the temperature varied only between 45°F and 75°F.

3. <u>Reduction of Sound Pressure Levels by Barriers</u>

(a) The reduction of sound pressure levels beyond that produced by geometric attenuation is shown in Figure 8. The barrier height and the sound shadow angle (θ) interest in varying degrees to produce a decrease in sound levels depending on the location of the receiver within the sound shadow zone.

(b) It can be shown also from Figure 8 that when a barrier is higher than a source of sound and the sound shadow angle is maximized ($\theta = 90°$), the maximum sound reduction will occur if the barrier is proximate to either the receiver or the barrier rather than at an intermediate location.

(c) Measurements by Merchant & Yantis show that low frequency sounds are less attenuated for given barrier heights and distances than

[1] John B. Lange, "Aircraft Noise and Sonic Boom", Transportation Noises, ed., Jas. D. Chalupnik, University of Washington Press, 1970, p. 5

frequency levels more than 1000Hz (see Table 3).[1]

(d) A listing of the elevation of the Mississippi River, its bluffs and the relief differential are tabulated in the Appendix for 21 port locations upstream from Alton Lock & Dam 26. The location with the lowest relief differential is 60 feet (Burlington, Iowa) while at Winona, MN and Eau Claire, Wisconsin the relief differential is the highest (560 feet).

(e) Calculations based on the noise reduction equation (used by Merchant & Yantis) show that a reduction of approximately 14dB above that accomplished by geometric attenuation would occur at Burlington, Iowa due to the barrier effect of the 60 foot bluffs.[2]

(f) If the bluffs were 560 feet high, then the noise reduction decrease due to the bluffs would be approximately 15dB.

(g) Assuming the average bluff relief differential is 271 feet along the Mississippi River as shown in Appendix 3, the noise reduction would be around 10dB.

4. Reduction by Vegetative Cover

(a) The loss of sound pressure levels due to vegetation cover is cited by Commins, et al.[3] A summary of propogation losses is shown in Table 4 due to three different types of vegetative cover along a test section of a high volume highway.

[1]H.C. Merchant & Michael R. Yantis, "Freeway Fencing as a Component of Noise Barriers" Noise-Con 73, Proceedings, 1973 Institute of Noise Control Engineering, (Ed. Noise News), Poughkeepsie, New York), Wash. D.C., Oct. 15-17, 1973, pp. 110-114.

[2]These calculations are based on a distance of 450 feet from the barge channel to the bluffs, a frequency of 250Hz and an ambient temperature of 70°F.

[3]D.E. Commins, B.A. Kugler, A.G. Pierson, "Evaluation of Highway Noise Propagation Based Upon Mean Energy Levels", Noise-Con 73 Proceedings, Wash., D.C., October 15-17, 1973, pp. 115-120

TABLE 3

Barrier Attenuation (dB)*

Barrier (ft) Height	Source Distance	Receiver Distance	Frequency (Hz) 31.5	63	125	250	500	1000	2000	4000	8000
6	75	50	0	0	1.3	4.3	7.3	10.3	13.3	16.3	19.4
6	200	200	0	0	0	0	2.1	5.1	8.1	11.1	14.1
6	200	100	0	0	0	0.8	3.9	6.9	9.9	12.9	15.9
7	200	100	0	0	0	2.2	5.2	8.2	11.2	14.2	17.2
8	200	100	0	0	0.3	3.3	6.4	9.4	12.4	15.4	18.4

* Calculations for the above table are based on the following equation:

$$NR = 10(\log N + 1)$$

$$N = \frac{2f}{C}\left\{R\left(\left[1 + \frac{H^2}{R^2}\right]^{\frac{1}{2}} - 1\right) + D\left(\left[1 + \frac{H^2}{D^2}\right]^{\frac{1}{2}} - 1\right)\right\}$$

and f = frequency in Hz
R = distance to barrier from source
D = distance to barrier from observer
C = velocity of sound in air
H = barrier height

Source: 1973 Institute of Noise Control Engineering, Proceedings, Noise Con, 1973 (ed. Noise/News, Poughkeepsie, New York), p. 111.

Table 4. Summary of Propagation Loss Factors For High Traffic Volumes

Site No.	Site Description	Propagation Loss Factor (ε)
1	Freshly plowed farmland	10.9 ± 0.5
2	Planted farmland (an asparagus field)	15.8 ± 0.7
3	Parkland (grass and shrubs)	15.4 ± 1.4

Source: 1973 Institute of Noise Control Engineering, Proceedings, Noise Con, 1973 (ed. Noise/News, Poughkeepsie, New York), p. 119.

(b) It can be seen from Table 4 that the propogation loss factor for freshly plowed farmland is 10.9 and is roughly equivalent to a 3.3B(A) decrease per doubling of distance. This is only slightly greater than would be expected due solely to geometric attenuation of sound produced by a line source.

(c) Planted farmland (the asparagus field) causes the most propagation loss (15.8dB(A) or a 4.8dB(A) reduction of sound levels with a doubling of distance.

(d) Parkland dover (grass and shrubs) induces a propagation loss of 15.4dB(A) or almost as much as the more lush asparagus cover.

(e) The results suggest that the existence of ground cover in the form of any type of vegetation will increase sound propagation loss significantly over the loss caused by geometric attenuation alone.

(f) Commins, et al, conclude that: (1) a lush vegetative cover will reduce dB(A) levels by a factor of 4.5 - 4.8dB(A) instead of 3dB(A) with a doubling of distance; (2) the propagation loss factor does not vary significantly up to heights of 15 feet above ground level and; (3) mean propagation loss factors appear to be stable for all traffic volume.

5. Refraction of Sound Due to Existing Lapse Rates

(a) The manner in which atmospheric lapse rates refract sound pressure waves is depicted in Figures 9a and 9b. When a normal lapse rate (temperature decreases with altitude) prevails as depicted by Figure 9a, a shadow region will develop. This effect develops because the sound wave fronts are bent upward causing a loss of sound pressure intensity at ground level beginning at the shadow region zone.

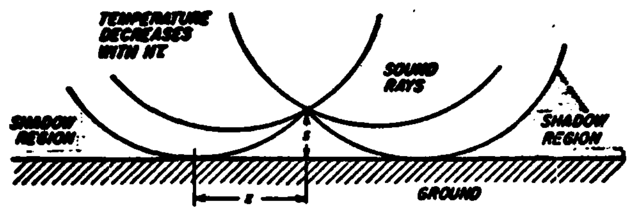


FIG. 9a Sound rays for an atmosphere with temperature lapse showing formation of shadow region.

Source: C.M. Harris, ed., Handbook of Noise Control (McGraw-Hill Book Co., 1957) p. 3-8.

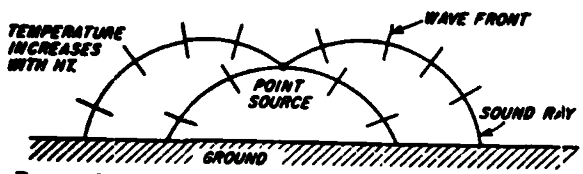


FIG. 9b Rays and wavefronts for an atmosphere with temperature inversion.

Source: C.M. Harris, ed., Handbook of Noise Control (McGraw-Hill Book Co., 1957) p. 3-8.

(b) When a temperature inversion exists (a reverse lapse rate) as shown by Figure 9b, the sound wave front is refracted towards the ground precluding the potential for a shadow region to develop. This phenomenon causes ground reflection to develop, intensifying sound pressure levels as they are propagated. Decibel levels, as a consequence, are higher at given distances than they otherwise would be based on geometric attenuation alone.

(c) The effects of atmospheric lapse rates have been investigated by Oliver, et al, and their results are shown in Figures 10a, b and c.[1] Mean dB(A) readings at the L_{50} level as shown by contour lines in Figures 10a and b were taken within a test region bordering a heavily traveled highway under normal lapse rate conditions.

(d) The same test region is shown at night when reverse lapse rates prevailed (Figure 10c). Visual evidence of how much lapse rates affect dB(A) levels experienced at varying distances from a line source of sound is made possible by comparing the dB(A) levels shown in Figures 9a, b and c at varying distances that would occur based solely on geometric attenuation (Figure 11).

(e) Oliver, et al, conclude that noise levels predicted under calm wind conditions during daytime hours with no consideration of existing lapse rates may be as much as 10dB(A) too high. Predicted dB(A) levels without consideration of the reverse lapse rates that typically prevail at night, likewise, will result in dB(A) levels that are too low.

[1]C.C. Oliver, R.A. Brown, & G.A. Wilson, "Meterological Effects on Noise Level Contours Near Highways", Noise-Con 73 Proceedings, Wash. D.C., Oct. 15-17, 1973, pp. 121-126.

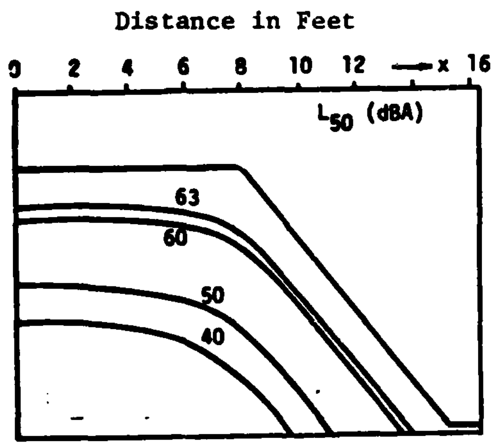


FIGURE 10a SUMMER DAY, NO WIND

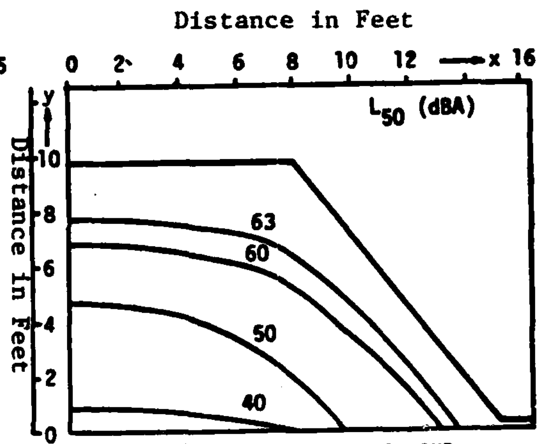


FIGURE 10b WINTER DAY, NO WIND

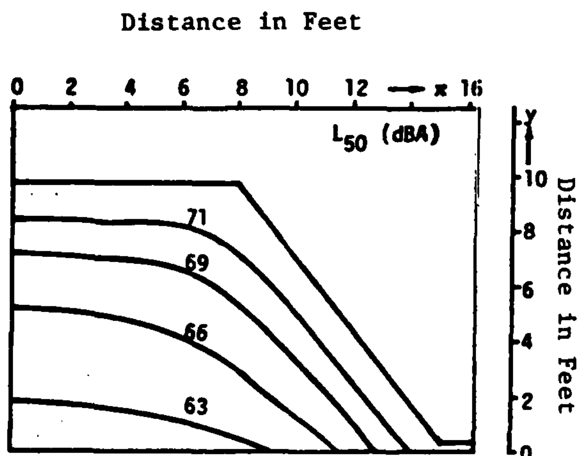


FIGURE 10c SUMMER EVENING, NO WIND

Sources: 1973 Institute of Noise Control Engineering, <u>Proceedings</u>, <u>Noise Con</u>, <u>73</u> (ed. Noise/News, Poughkeepsie, New York), p. 126.

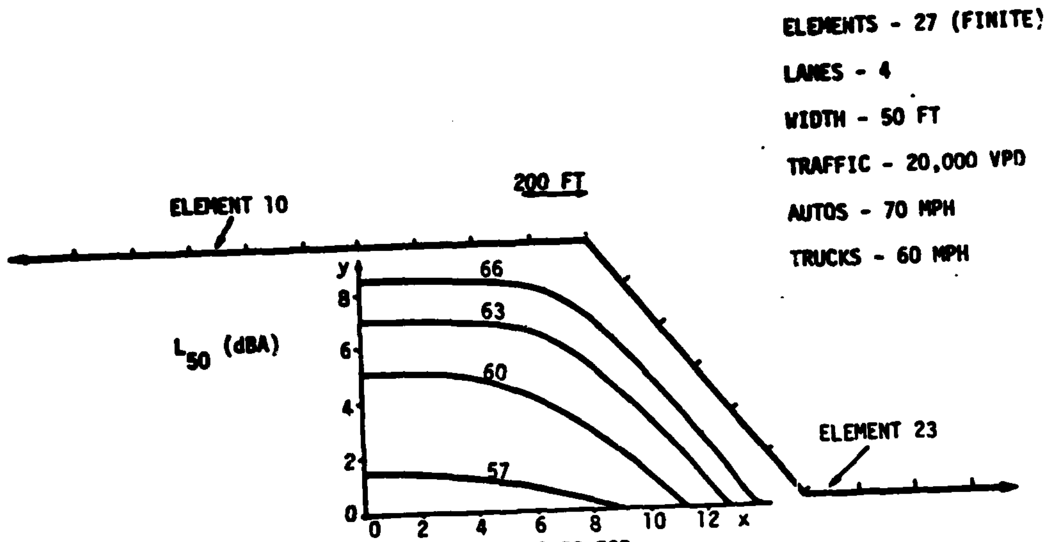


FIGURE 11 MODEL AND BASELINE CONTOURS FOR STUDY OF WEATHER EFFECTS

Source: 1973 Institute of Noise Control Engineering, Proceedings, Noise Con, 73 (ed. Noise/News, Poughkeepsie, New York), p. 125.

6. <u>Refraction of Sound in the Atmosphere Due to Wind Structures</u>

(a) Wind structures, as shown in Figure 12, affect sound propagation somewhat the same way as prevailing lapse rates. Wind velocities normally increase with altitude. As a result refraction of the sound wave front upward occurs in an upwind direction. A shadow region, develops upwind from the sound source and, as a result, decreased dB levels are experienced. Downwind from the noise source, however, the sound pressure front is refracted toward the ground and there is not the corresponding decrease in intensity of sound pressure as occurs upwind.

(b) Oliver, et al, have investigated wind structure effects on propagation of sound energy, also. The effect of wind direction is shown in Figures 13a and b. It becomes apparent when examining Figures 13a and b that a wind blowing directly upwind or downwind from a line source of sound results in lowered dB(A) levels. This effect can be verified by examining the noise contour levels depicted in Figure 11 and comparing it to the levels shown in Figures 13a and b.

(c) It is important to note that normal lapse rate structures exert a greater attenuation effect usually than wind structures (compare Figures 10a and b with Figures 13a and b), unless wind velocities are abnormally high.

(d) Oliver, et al, conclude that if the effects of the normal range of wind and temperature structures are considered in predicting noise levels, then predicted values in an upwind direction would be at least 6dB(A) less and 3dB(A) less in a downwind direction during daytime hours compared to predicted values based on geometric attenuation alone.

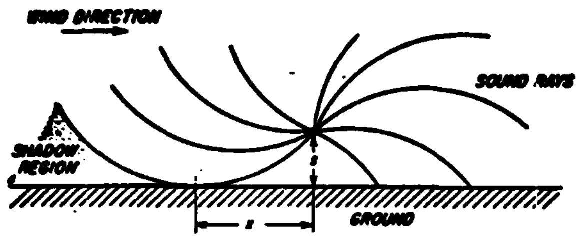


Fig. 12. Sound rays for an atmosphere with wind gradient, showing shadow formation upwind.

Source: C.M. Harris, ed., Handbook of Noise Control (McGraw-Hill Book Co., 1957) p. 3-8.

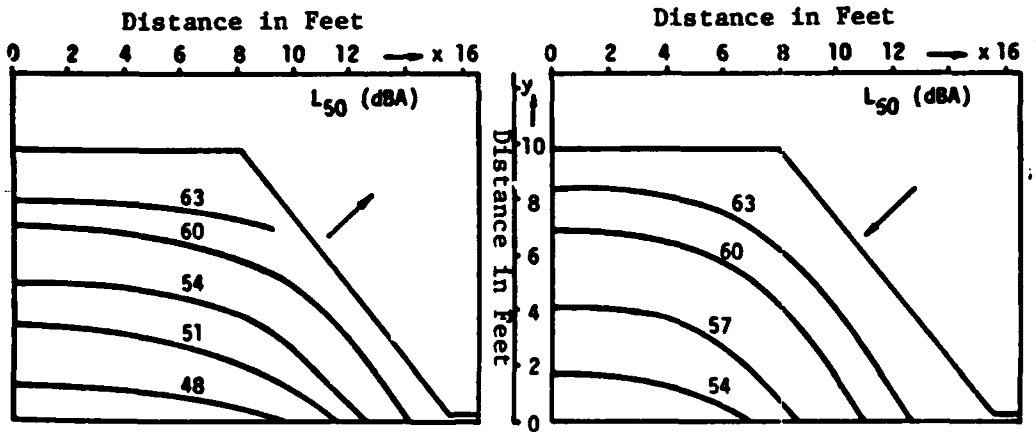


FIGURE 13a SUMMER DAY, 45° WIND

FIGURE 13b SUMMER DAY, 225° WIND

Sources: 1973 Institute of Noise Control Engineering, Proceedings, Noise Con, 73 (ed. Noise/News, Poughkeepsie, New York), p. 125.

III. The Effects of Noise on People

A. Health, by convention, is the primary criterion used to guage the effects of noise on people because it encompasses all of the negative aspects of sound as an element of the physical environment. Health problems that arise due to direct or indirect effects of noise involve two facets: (1) Noise is a hazard that is disruptive to physiological functions and; (2) Noise can be an annoyance and, as such, will provoke subjective and unconscious responses such as resentment, irritability and other aspects of abnormal behavior. The physiological damage caused by noise is generally more severe than the psychological problems of annoyance and irritability.

B. The effects of noise on health represent a continuum from hazards to less severe nuisances as shown in Figure 14. The elements presented in Figure 14 show that the hazards caused by noise consist of communication interference, temporary and eventually permanent hearing loss and a host of responses caused by noise impinging on various sensory and neural organs.

1. Communications interference not only masks hearing under circumstances where a communication can mean the difference between life and death but can cause distraction which contributes to deterioration of operator performance.

2. Permanent hearing loss induced by long-time exposures to intense noise levels can become a matter of economic security for an individual besides degrading his ability to survive in situations where only sound can convey a message of impending danger. Several studies indicate that workers suffering from occupational hearing losses risk job security

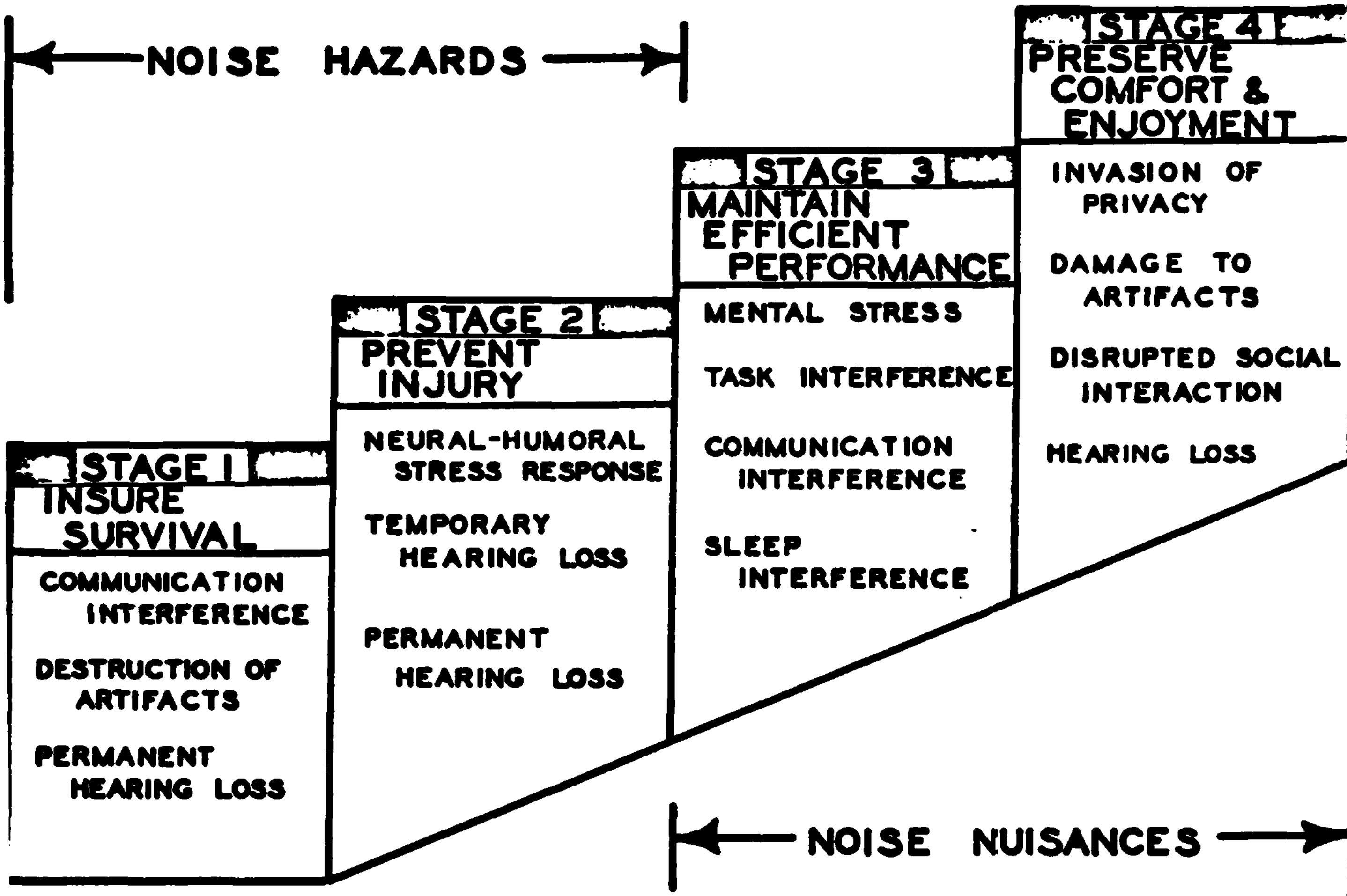


FIGURE 14. *Noise and its implicated health effects*

Source: C.R. Bragdon, Noise Pollution (University of Pennsylvania Press, 1970), p. 64.

because of the examining physician's fear that he will be held responsible if the worker is involved in an accident. If the worker wishes to change jobs and has been rendered even partially deaf because of his occupation, many employers will discriminate against him because of alleged high insurance costs.[1]

3. Neural-heumoral stress responses are caused by noise acting as an agent of physiological stress. Stress implies a change in conditions affecting an organism which requires a compensatory effort to maintain necessary functions and when a load (noise) impinges on the organism, it must modify its behavior in order to continue functioning. The compensatory or adaptive responses to noise loads (stress) can lead to physiological changes which in turn produce human dysfunctioning. Noise, therefore, can cause the body to respond with a variety of hormonal and neurological mechanisms which when prolonged consistently can lead to the following disorders:

(a) ulcers

(b) hypertension

(c) colitis

(d) migraine headaches

(e) high blood pressure

(f) nervous disorders

(g) phychosomatic illnesses

1See H. Davis & R.S. Silverman, Hearing & Deafness (rev. ed.; NY; Holt, Rinehart & Winston, 1962) p. 511 and C.R. Bragdon, Noise Pollution, University of Pennsylvania Press, Philadelphia, 1971, p. 68.

IV. Effects of Noise Created by Alternate Modes of Transport

A. Acceptable Exposures to Dangerous Noise

1. Identification of acceptable noise exposure begins wit h measurement of sound levels. Acceptable exposures to dangerous noise (see Table 5) as prepared by the National Academy of Science have been worked out on the basis of duration and repetition as well as sound levels.

2. It is convenient to grade the severity of a noise exposure by the "noise-exposure rating" which is defined as the ratio of the duration of a dangerous noise to that allowed as shown in Table 5.[1] A noise exposure is considered acceptable for all values of exposure ratings that do not exceed unity. The hazard to hearing increases as the noise exposure rating progressively attains values exceeding unity.

3. An examination of Table 5 shows that dangerous noise levels begin at 89dB(A) for the occupational situation and it is of interest to ascertain what transportation noises exceed the 89dB(A) threshold level. The range of noise levels for various transportation units is shown in Table 6 and an examination of the data reveals that nearly all of them exceed 89dB(A) in their operational ranges.

4. A strict duration and intermittency analysis of some of these transportation noise sources would show no hazard to hearing of the public as shown by Table 5 standards for occupation situations, but this does not mean that no permanent effect could occur. This methodology, as outlined above, measures exposures defined as acceptable only if the hearing acuity necessary to understand speech is affected. Intermittent exposures to

[1]James H. Botsford, "Damage Risk," Transportation Noises, ed., James D. Chalupnik, University of Washington Press, Seattle, 1970, pp. 106-110.

Table 5

ACCEPTABLE EXPOSURES TO DANGEROUS NOISE

To use the table, select the colun headed by the number of times the dangerous noise occurs per day, read down to the average sound level of the noise and locate directly to the left in the first column the total duration of dangerous noise allowed for any 24 hour period. It is permissible to interpolate if necessary.

Total Noise Duration Per Day (24 hours)	Number of Times Noise Occurs Per Day						
	1	3	7	15	35	75	160 up
8 hrs.	89	89	89	89	89	89	89
6	90	92	95	97	96	94	93
4	91	94	98	101	103	101	99
2	93	98	102	105	108	113	117
1	96	102	106	109	114	125	125 (1½h)
30 min.	100	105	109	114	125		
15	104	109	115	124			
8	108	114	125				
4	113	125					
2	123						

A-Weighted Sound Levels

Source: J.D. Chalupnik, ed., Transportation Noises (University of Washington Press, 1970) p. 107.

Table 6

TRANSPORTATION SOUND LEVELS

Number of units measured is shown in parenthesis.

Number of units measured is shown in parenthesis.

Miscellaneous vehicles, maximum noise at operators ear	
cranes (2)	85-113 dBA
outboard motor	85
street sweeper	96
busses (6)	82-96
trucks (9)	81-92
tractors (7)	85-113
road graders (3)	97-100
self-propelled camper	92
Power boats, at seat nearest motor*	
cruising speed (7)	83-104 dBA
full speed (3)	88-95
River barge tow boat, 919 tons gross	
engine room	101-112 dBA
shop, steering room	94-98
other rooms	73-78
Diesel tractor-trailer trucks, at drivers ear (22)	
engine 400-700 rpm	68-79 dBA
engine 1000-1500 rpm	75-87
engine 2000-2500 rpm	82-92
Alaskan airliner cockpits (22)**	
taxi	73-91 dBA
take-off	80-119
climb	73-102
cruise	78-99
Mining equipment, at operators ear+	
trucks, 15 ton up	89-101 dBA
shovels, diesel	91-107
shovels, electric	83-91
bulldozers	102-106
cranes	88-99
end loaders	95-97
road graders	91-96
locomotives, diesel	88-100

Source: J.D. Chalupnik, ed., Transportation Noises (University of Washington Press, 1970) p. 110.

90 plus dB(A) levels could lead to impairment short of this effect but still be significant from the public standpoint if not the industrial physician's viewpoint.

5. FHWA and HUD, in fact, have adopted a set of far more stringent standards as applied to different land-use categories in the design of urban highways. Design noise level and land-use relationships developed by FHWA are shown in Table 7. A comparison of HUD and FWHA noise standards for the residential land-use category (B) is illustrated in Figure 15.

6. The descriptors and standards shown in Table 7 and Figure 15 show that the maximum noise levels imposed by HUD and FHWA as they affect transportation modes are considerably more stringent than the 89dB(A) level deemed as the threshold level for occupaitonal situations. It should be pointed out that most of the land adjacent to rivers utilized by barges would fall in category C as described in Table 7. As can be seen from Table 7, design noise levels of 75dB(A) at the L_{10} level are permissable for land-use category C. This means that passing barge craft could exceed 75dB(A) as long as 75dB(A) was not exceeded 10 percent of the time during the busiest hours of the day.

B. Non-Physical Factors Affecting Group and Individual Perception of Noise

1. Borsky has offered the following factors as among the most significant in predisposing psychological acceptance or hostility toward the same noise exposures:

(a) Feelings about the necessity or preventability of the noise;

(b) Feelings of the importance of the noise source and the value of its primary functions;

TABLE 7

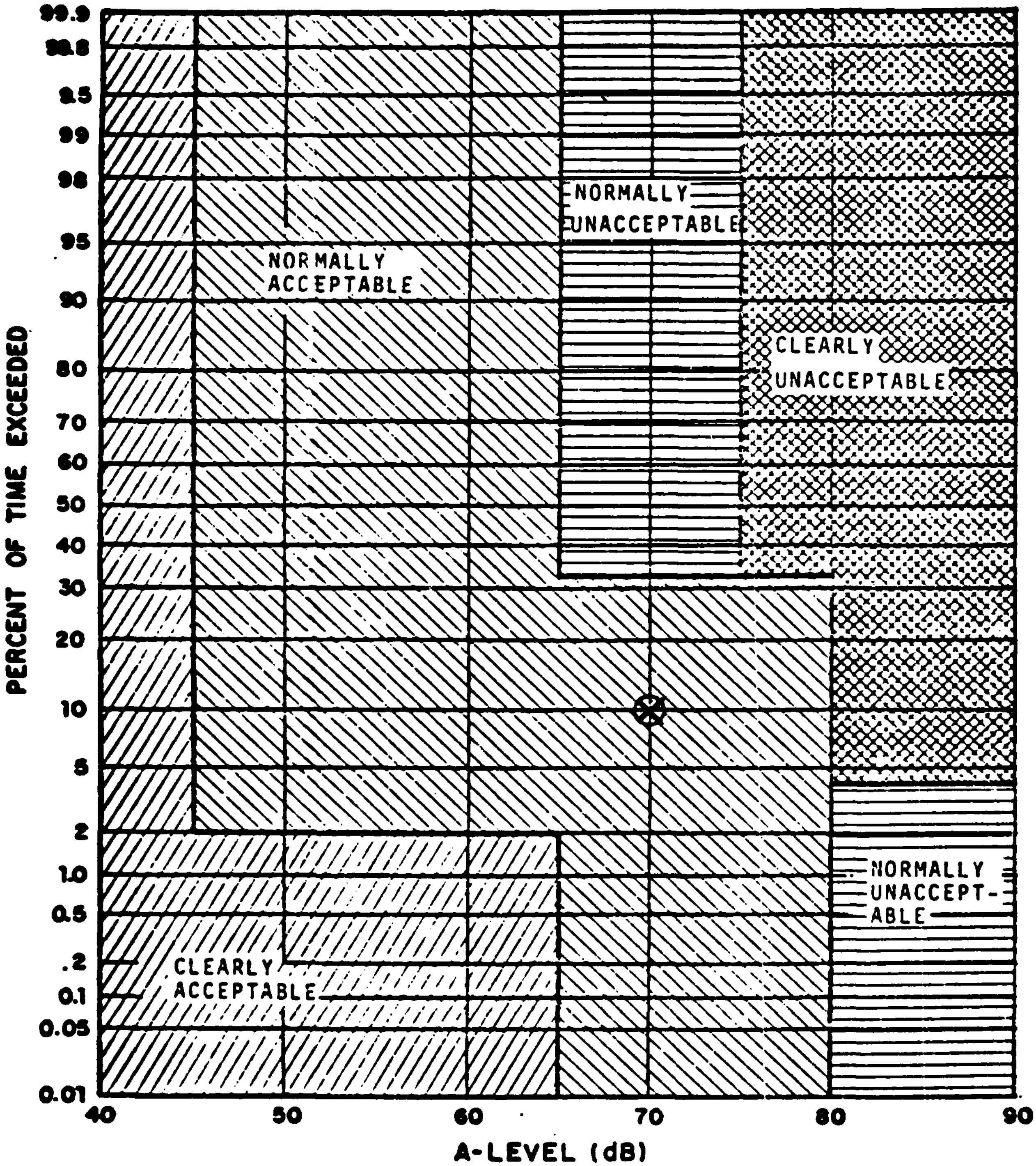
DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS

Land Use Category	Design Noise Level - L_{10}	Description of Land Use Category
A	60 dBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	For requirements on undeveloped lands see paragraphs 5.a.(5) and (6) of PPM 90-2.
E*	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

Source: Federal Highway Administration, Noise Standards & Procedures, (National Technical Information Service, 1972) p. 177.

FIGURE 15

COMPARISON OF HUD AND FHWA NOISE STANDARDS



CURRENT HUD CRITERIA FOR NON-AIRCRAFT NOISE

⊛ - FHWA Design Noise Level for land use category B (residential).

Source: Federal Highway Administration, Noise Standards & Procedures, (National Technical Information Service, 1972) p. 198.

(c) The extent to which other things are disliked in the residential environment;

(d) Belief in the effect of noise on general health;

(e) The extent to which fear is associated with the noise.[1]

2. McKennell further states that the following social factors are salient in considering the impact of noise originating from a transportation source: (a) occupational class; (b) educational level; (c) value of residence; (d) membership and affiliation in organizations, and; (e) degree of political activity and citizen participation.[2] These factors identify a certain type of individual who will complain of annoyances caused by noise quite readily. According to McKennell, these complaintants come from the middle class stratum, but that section which is better educated, more politically active and more articulate than the average middle class citizen. He found no evidence that as a group they were any more neurotic than the non-complaintants equally irritated by the same noise source. They tended to be genuinely convinced that the noise could be prevented and that it was adversely affecting their health.

C. An Example of Railroad Noise Effects on a Selected Population Group

1. A sudden cessation of barge service or even a limit to further cargo transportation by barges could result in a dramatic increase in railroad traffic. While freight trains are not relied upon nearly as

[1] Paul N. Borsky, "The Use of Social Surveys," Transportation Noise, ed., James D. Chalupnik, University of Washington, Seattle, 1970, pp. 219-27.
[2] Aubrey C. McKennell, "Complaints & Community Action," Transportation Noises, ed., James D. Chalupnik, University of Washington, Seattle, 1973, pp. 229-44.

much in the U.S. as in the U.S.S.R., a study carried out in Moscow points to some of the problems that might be encountered in urban areas of the U.S. if a sudden increase in the frequency of rail traffic occurred.[1]

2. This study (The Assessment of Railway Traffic Noise by the Population) focuses on mass complaints of high noise levels from a population living near railroad tracks. The protests prompted a study on public reaction and a verbal association test was chosen as the main criterion to measure noise impact on the population. At the time the study was initiated, 87 percent of the population had filed complaints. Questionnaires were distributed among the inhabitants in order to measure subjective reactions to the railway noise. Of the 144 persons residing in the affected area 40-100 meters from the railroad tracks, 126 (87 percent) complained of intense discomfort and disturbance; 47 persons (64 percent) reported interruption of sleep owing to heavy traffic in the early morning hours; and 21 (45 percent) complained that noise from the trains and signals caused fear in their children. Inhabitants in the 150-200 meter range reported less discomfort; about 50 percent had serious complaints. Those inhabitants living 250-300 meters from the railroad reported that the noises were very noticeable and irritating but did not constitute a real disturbance.

3. A verbal association test was given to the 136 persons in the 40-100 meter range in order to determine the effect of the railroad noise.

[1]The Assessment of Railway Traffic Noise By The Population (Questionnaire Data and Verbal Association Experiment) by A.M. Volkhov, I.L. Kargodina and A.I. Tyssar, The All-Union Scientific Research Institute of Hygiene in Railway Transport/U.S.S.R. (NTIS PB-228-345, Noise Facts Digest, p. 87)

Response or reaction time to key words as well as general words was noted compared to a control group not affected by railroad noise. The group living within the 40-100 meter range of the tracks exhibited the most delayed response time of any test group. The response time for all test groups is shown in Table 8.

Table 8

Distance from Railroad Tracks (in meter)	Maximum Noise Levels with Windows Open (in dB(A))	Latent Verbal Response Time to Work (in seconds) General	Key
40-100	84	3.3	4.3
150-180	67	2.7	3.7
250-280	63	2.4	3.4
Control Group	-	2.6	3.2

4. The study, according to the author, shows how citizens in a community can be affected by high noise levels. The analysis demonstrated that high noise levels have an adverse effect on the central nervous system which is manifested by a delayed response as well as a delayed latent response time in verbal speech tests.

V. Noise Levels Created By Alternative Modes of Transportation

A. Relationships of Decibels to the A-weighted Network

1. Sound pressure levels produced by transportation modes are not usually described in decibels (dB) in the attempt to most closely simulate the perceived impact by the population. They are set, as mentioned in Section I, to a weighted scale known as the A-weighted network (dB(A)). Equivalent dB(A) intensity levels are shown in Figure 16 and the sound intensity levels radiated by surface transportation modes are normally converted from dB to dB(A).

2. Frequently, noise levels produced by surface modes of transportation are described in the perceived noise level scale (PN&B) which is directly converted to dB(A) levels by subtracting a factor of 13. The perceived noise level scale is used mainly for aircraft originated noises rather than sound levels emitted by surface modes of transportation.[1]

B. Highway and Street Noises

1. Noises produced by automobiles and trucks permeate the typical urban or suburban community because of the ubiquitous nature of roads, highways and streets. The cumulative distribution of highway vehicles versus noise levels is depicted in Figure 17. An examination of Figure 17 reveals that if noise levels exceed 80 dB(A) 50 feet from the edge of the highway, then only 10 percent can be attributed to automobile traffic. The remaining 90 percent of the 80 plus dB(A) noise levels would be due to gasoline and diesel powered trucks.[2]

[1] C.R. Bragdon, Noise Pollution, University of Pennslyvania Press, Philadelphia, 1970, p. 62.

[2] U.S. Department of Transportation, Transportation Noise and Its Control, U.S. Government Printing Office, Washington D.C., 1972, p. 10

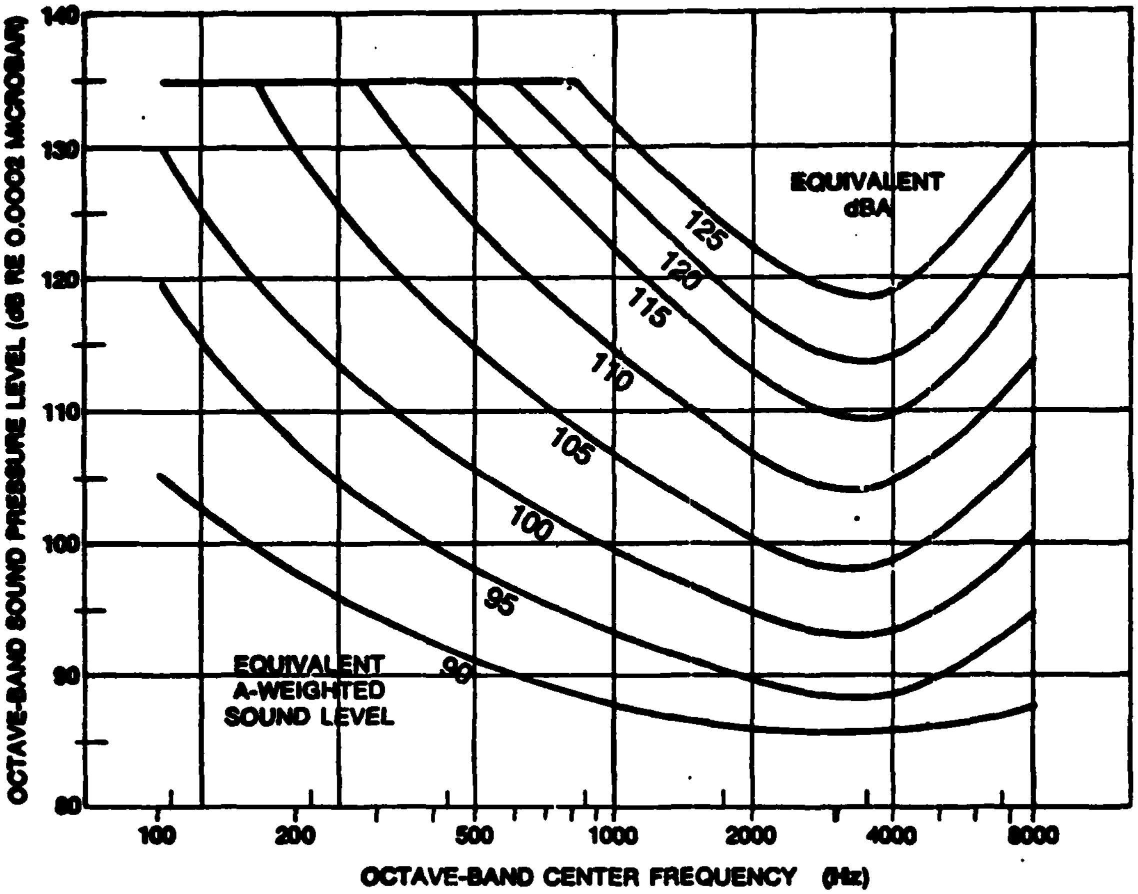
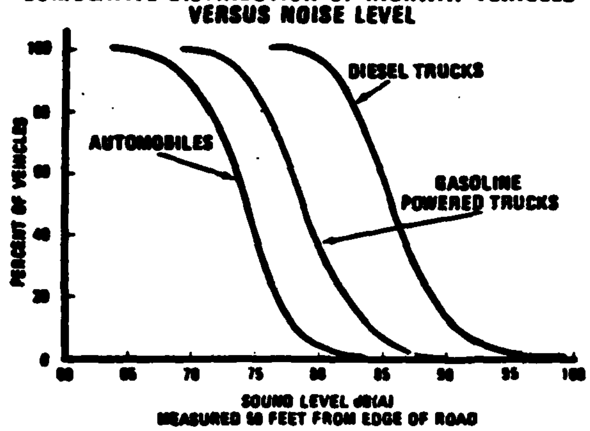


FIGURE 16 *Contours for determining equivalent A-weighted sound level.* Source: Federal Register, *May 10, 1969.*

Fig. 17 CUMULATIVE DISTRIBUTION OF HIGHWAY VEHICLES VERSUS NOISE LEVEL



Source: U.S. Department of Transportation, Transportation Noise and Its Control. (Superintendent of Documents, U.S. Government Printing Office, 1972), p. 10.

2. The graphs portrayed in Figure 18 show that only a small percentage of trucks (from 2.5 percent to 20 percent) will boost dB(A) levels as much as 8-13dB(A) over noise levels generated solely by automobiles. If the density of traffic on a highway equals or exceeds 1,000 vehicles per hour, then 90dB(A) levels are attained when 20 percent of the traffic is made up of trucks. The Department of Transportation states that with a density of 100 vehicles per mile averaging 50 miles per hour, four trucks will emit as much noise as 84 automobiles.

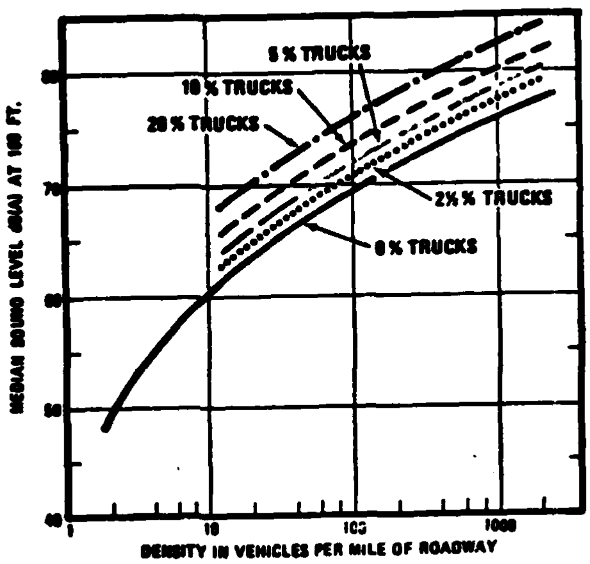
3. C.R. Bragdon points out that in a traffic noise survey carried out in Philadelphia, trucks of all types averaged out as the third noisiest source of transportation (see Figure 19).[1] He makes the point that if the truck noise sample included only over-the-road tractor-trailer trucks, the noise levels would have been substantially higher. An examination of Figure 19 discloses that at locations of 15 feet or less from the roadside, where many residential and commercial buildings are often situated, the outside noise levels from passing truck traffic will be in excess of 85dB(A).

4. Because of their design, the over-the-road tractor-trailer trucks will radiate large amounts of acoustic power. This type of truck cruising at 45 miles per hour will produce more than 87dB(A) at a 50-foot distance on a level grade. A 3-5 percent upgrade will cause a tractor-trailer rig to produce an additional 2-3dB(A) and during acceleration, another 5dB(A) will result.[2]

[1]C.R. Bragdon, Noise Pollution, University of Pennsylvania Press, Philadelphia, 1970, p. 115

[2]U.S. Department of Transportation, Transportation Noise and Its Control, U.S. Government Printing Office, Washington D.C., 1972, p. 11.

Fig. 18 **MEDIAN NOISE LEVEL ESTIMATES OF MIXED TRAFFIC at 50 MPH**



Source: U.S. Department of Transportation, <u>op cit.</u>, p. 11.

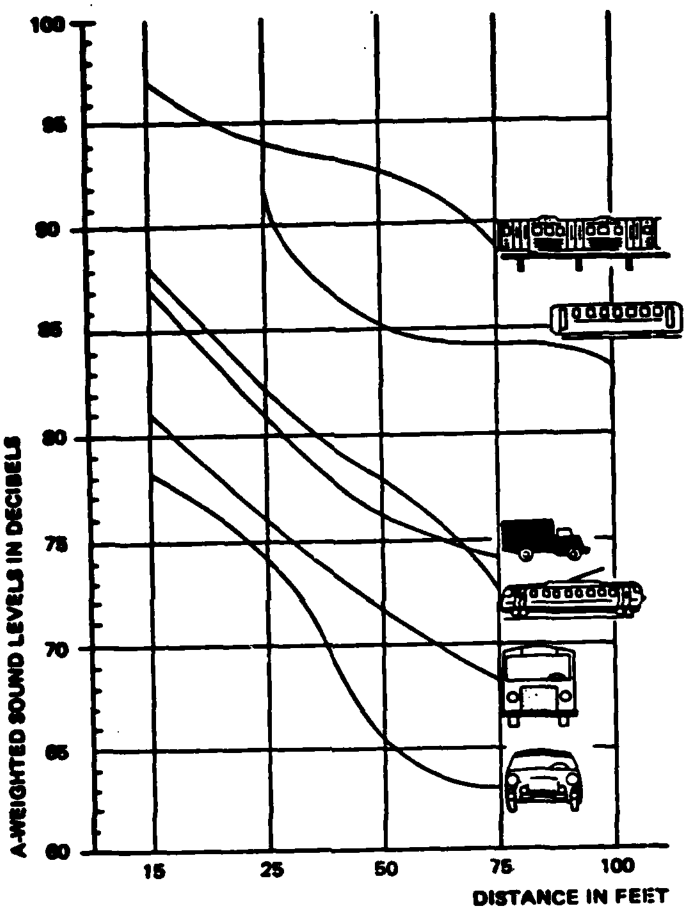


Fig. 19 Distance as a factor in noise intensity: Survey of specific noise sources.

Source: C.R. Bragdon, op. cit., p.11.

5. Engine and exhaust noises from trucks do not vary appreciably with changes in highway speed because they operate on open highways within a standard operating r.p.m. range. The largest variations caused by truck engine and exhaust noise will depend on the muffler equipment the truck possesses. The typical stock mufflers provided by the vehicle manufacturer will depress truck noise levels 4-6dB(A). Tandem mufflers, if used, will achieve 6-8dB(A) noise reductions.

6. Many independent owner-operators of over-the-road tractor-trailer trucks, unfortunately, will remove or else let the standard stock mufflers deteriorate in order to improve performance.[1] When this occurs, heavy trucks will emit noise levels in excess of 95dB(A).

7. Tire/pavement interaction at typical open highway speeds (over 55 miles per hour) becomes the dominant source of noise for trucks exceeding the noise levels produced by the engine-exhaust system. A tractor-trailer rig with 18 tires will generate 95dB(A) to as much as 102dB(A) at a 50-foot distance, depending on the tire tread design.[2]

8. The perceived impact of truck generated noise as experienced by a selected population in the northeastern states is shown by Figure 20.[3] The scale in Figure 20 shows that heavy trucks are perceived to emit more noise energy than any form of surface transportation except for subways.

C. Railroad Noises

[1]National Technical Information Service, Noise Standards & Procedures, FHWA, U.S. Department of Commerce, Washington D.C., 1972, p. 5

[2]U.S. Department of Transportation, Transportation Noise and Its Control, U.S. Government Printing Office, Washington D.C., 1972, p. 12

[3]U.S. Department of Transportation: Recommendation for Northeast Corridor Transportation, Final Report, vol. 1 and 3, National Technical Information Service, Springfield, Va., September, 1971, p. 62-63.

Sound source	dB (A)*	Response criteria
	150	
Carrier deck jet operation	140	
		Painfully loud
	130	Limit amplified speech
Jet takeoff (200 ft)	120	
Discotheque		
Auto horn (3 ft)		Maximum vocal effort
Riveting machine	110	
Jet takeoff (2000 ft)		
Shout (0.5 ft)	100	
N.Y. subway station		Very annoying
Heavy truck (50 ft)	90	Hearing damge (8 hr)
Pneumatic drill (50 ft)		
	80	Annoying
Freight train (50 ft)		
Freeway traffic (50 ft)	70	Telephone use difficult
		Intrusive
Air conditioning unit (20 ft)	60	
Light auto traffic (50 ft)		
	50	Quiet
Living room		
Bedroom	40	
Library		
Soft whisper (15 ft)	30	Very quiet
Broadcasting studio	20	
	10	Just audible
	0	Threshold of hearing

*Typical A–Weighted sound levels taken with a sound-level meter and expressed as decibels on the scale. The "A" scale approximates the frequency response of the human ear.

Fig. 20 Weighted sound levels and human responses.

Source: U.S. Department of Transportation, Recommendations for Northeast Corridor Transportation, Final Report, v. 3. (National Technical Information Service, 1971) p. C2-3.

1. As the best alternative mode of transportation for carrying low value, bulk or heavy cargo, rail service could provide the service that is currently afforded by intra-coastal and river barges.

2. Several studies have been accomplished concerning the role of rail transportation in contributing to community noise levels. In a survey of noise pollution sources in Philadelphia, Penn Central commuter trains were shown to produce an average noise level of 92dB(A) 25 feet away and 85dB(A) at 50 feet (see Figure 19). This study was conducted in an urban environment where there was a number of reflective surfaces and because of the myriad reflections of noise, the inverse square law as applied to noise attenuation did not operate as in an "open-field" or rural environment. The effect of an urban environment on attenuation of noise is illustrated in Table 9.[1]

3. A U.S. Department of Transportation study shows that diesel-powered freight trains produce 120 PNdB at a distance of 50 feet when traveling at 30 to 50 miles per hour (see Figure 21).[2] A perusal of Figure 21 shows that a distances of 100, 200, 500, and 1,000 feet, the PNdB levels generated by the train were 115, 110, 105 and 94, respectively. This study was carried out in a mixed rural and urban environment and reveals that attenuation of noise occurred at a greater rate than would occur based solely on geometric attenuation. This appears to further substantiate the empirical evidences of the effects of other noise attenuation factors discussed in Section II.

[1]C.R. Bragdon, Noise Pollution, University of Pennsylvania Press, Philadelphia, 1970, p. 124.

[2]U.S. Department of Transportation, Recommendation for Northeast Corridor Transportation, Final Report, vol. 1 and 3, NTIS, Springfield, Va., September 1971, p.c. 2-18.

TABLE 9. Noise Level as a Function of Horizontal Distance: Ground Transportation

Noise Source	Horizontal Distance from Noise Source				
	15 ft.	25 ft.	50 ft.	75 ft.	100 ft.
Elevated Subway	97 dBA	94 dBA	93 dBA	89 dBA	
Train	-	92 dBA	85 dBA	85 dBA	83 dBA
Trolley	88 dBA	82 dBA	78 dBA	72 dBA	
Truck	87 dBA	81 dBA	76 dBA	74 dBA	
Bus	81 dBA	76 dBA	72 dBA	68 dBA	
Automobile	78 dBA	74 dBA	65 dBA	63 dBA	

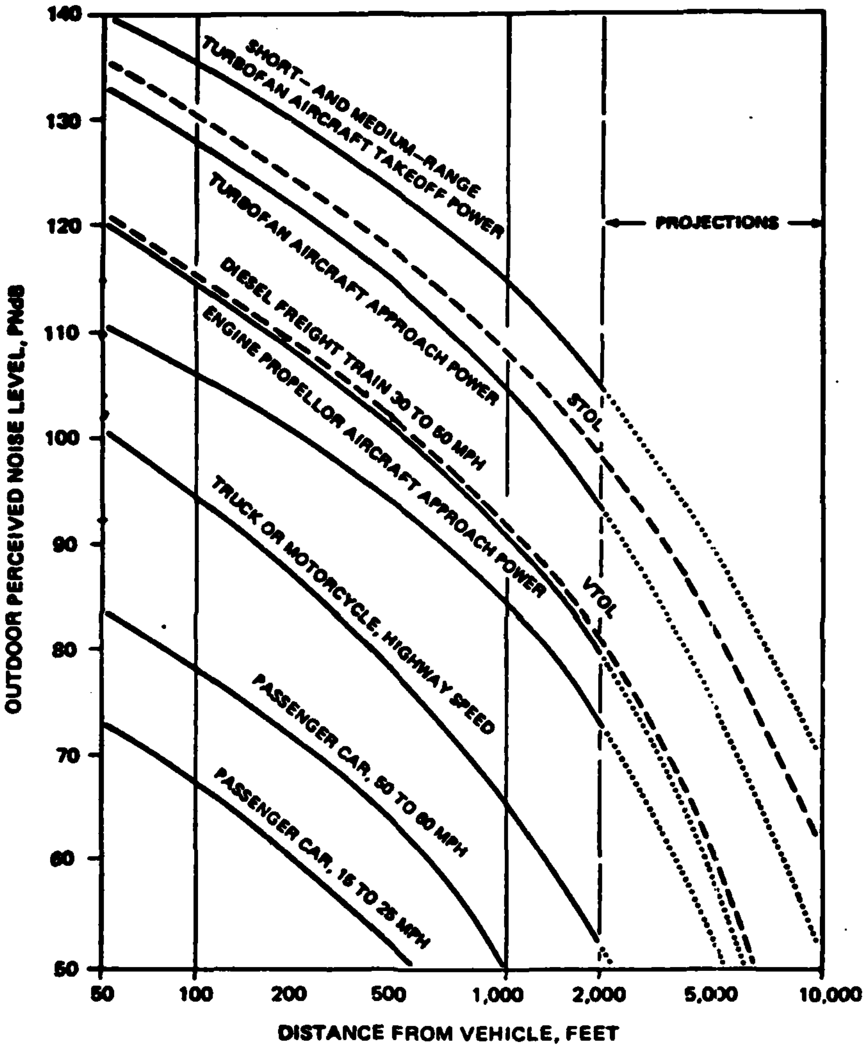


Fig. 21 **Typical PNdB values for vehicles noises heard at a distance.**

Source: U.S. Department of Transportation, op. cit., p. C2-17.

4. As is the case for trucks, the range of noise intensities emitted by trains is dependent on several variables. In Figure 20, freight trains were shown to emit only 74dB(A) at a distance of 50 feet under certain circumstances. Obviously speed, throttle, settings, the number, mix and age of cars the locomotive is pulling, and the condition of the track constitute some of the variables affecting the sound intensity levels generated by trains. The following discussion takes into account some of these variable factors:

(a) A diesel locomotive has eight throttle settings. Engine power and noise levels increase with throttle position (Table 10), ranging from 69.5dB(A) at idle to 89.0dB(A) at throttle position eight. The major components of locomotive noise appear to be in order of significance: (1) engine exhaust noise, (2) casing-radiated noise, (3) cooling fan noise and, (4) wheel/rain noise, all of which increase with throttle settings. The noise contributors of each one of these locomotive components is listed in Table 11. The noise signature (range of frequencies) of one of the more common makes of locomotives is revealed in Figure 22. As can be seen, the major portion of locomotive sound intensity levels is emitted between 100-2,700Hz, with peak levels occurring in the 500-650Hz range.

(b) Measured locomotive noises are shown in Figure 23 for 105 pass-by events. The range at 100 feet is 74dB(A) to 98dB(A).

(c) The maximum sound level as a function of the velocity is shown by Figure 24 for the same 105 pass-by events. As far as the locomotive is concerned, there appears to be no relationship between noise levels emitted and speed.

Table 10

Effect of Throttle Position on Engine Power and Noise Levels

Throttle Position	Percent of Rated HP for Diesel Engines	Percent of Time at Throttle Position: Road Locomotive	Switches	dB(A) at 100 Ft. for 2000 HP Engine
Idle	0.75*	41	77	69.5
1	5	3	7	72.0
2	12	3	8	74.0
3	23	3	4	77.0
4	35	3	2	80.0
5	51	3	1	84.5
6	66	3	-	86.0
7	86	3	-	87.5
8	100	30	1	89.0**

*Three cooling fans operate during throttle position 8, while only one fan operates at all other positions.

**Locomotive auxiliary HP only - no traction.

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Control, Washington D.C., p. 4-8.

TABLE 11 *

SOURCE CONTRIBUTIONS TO LOCOMOTIVE NOISE LEVELS

Source		dB(A) at 100 Ft (Throttle 8)
Exhaust		86 -93
Casing		80--85.5
Cooling Fans		80 84
Wheel/Rail at 40 mph	Locomotive only	78
	Total train	81

*Locomotive noise levels are predicted by the D.O.T. as shown above and employ the following formula:

dB(A) at 100 ft. = 92 + 10 log (Lp/1500) - 3 (8 throttle settings) - T where T is 6 for turbocharged engines and 0 otherwise and the prediction involves:

(1) determining the mechanical power and type of engine required to perform a given task;

(2) determining the throttle setting required to perform a given task;

(3) converting from engine type and throttle setting to sound level.

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Control, Washington D.C., p. 9-15.

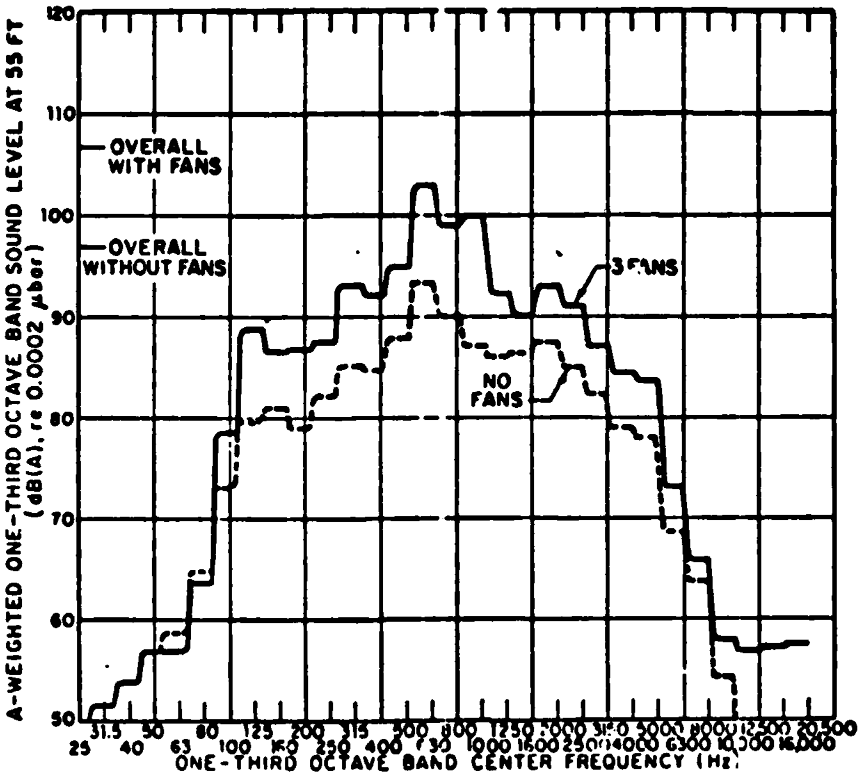


Figure 22. Effect of Fan Noise on the A-Weighted Spectrum of EMD GP40-2 Locomotive Noise at 55 ft (Engine Access Doors Open)

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Control, Washington D.C., p. 4-15.

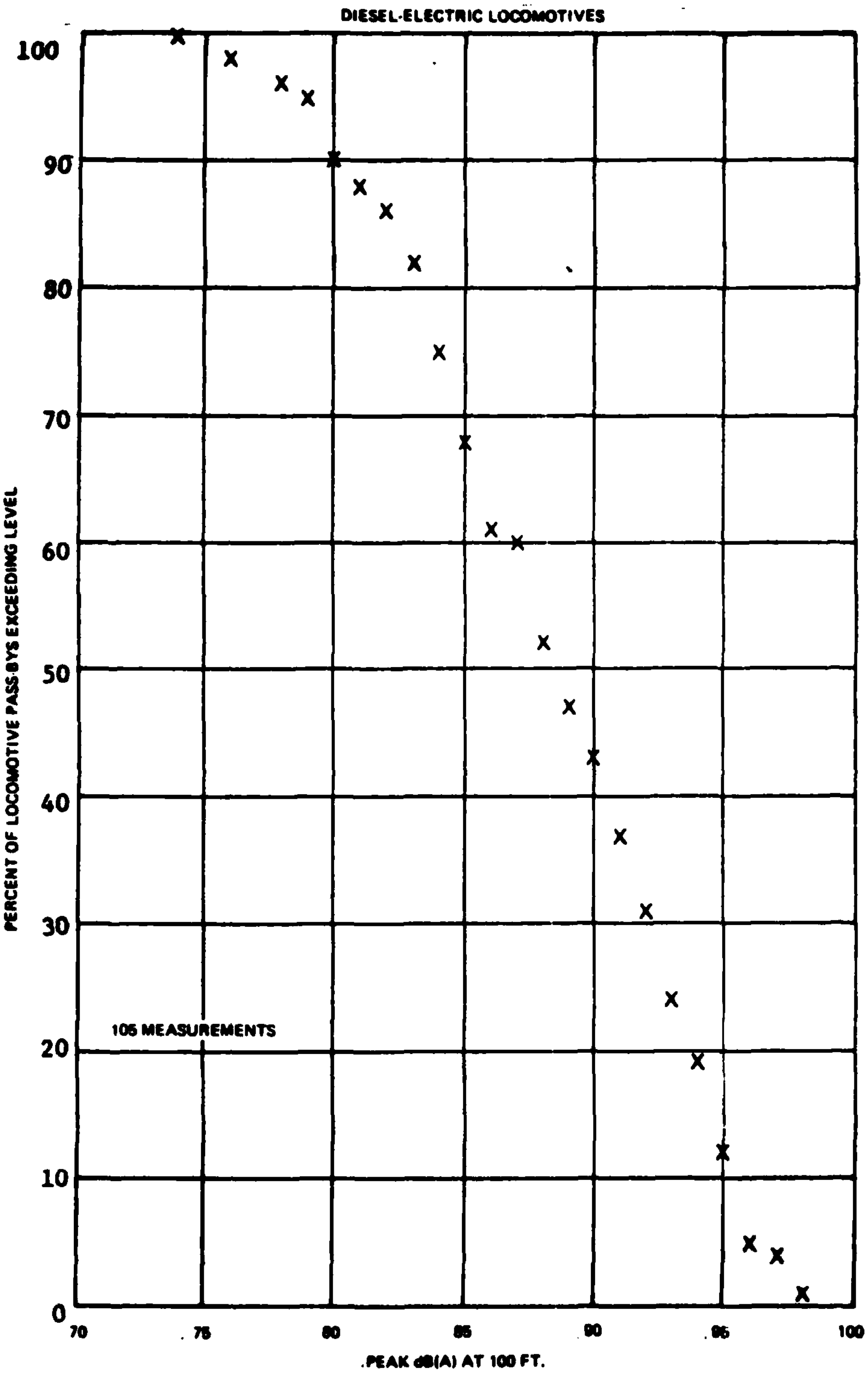


Figure 23. Diesel-Electric Locomotive Pass-Bys

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Control, Washington D.C., p. 4-17.

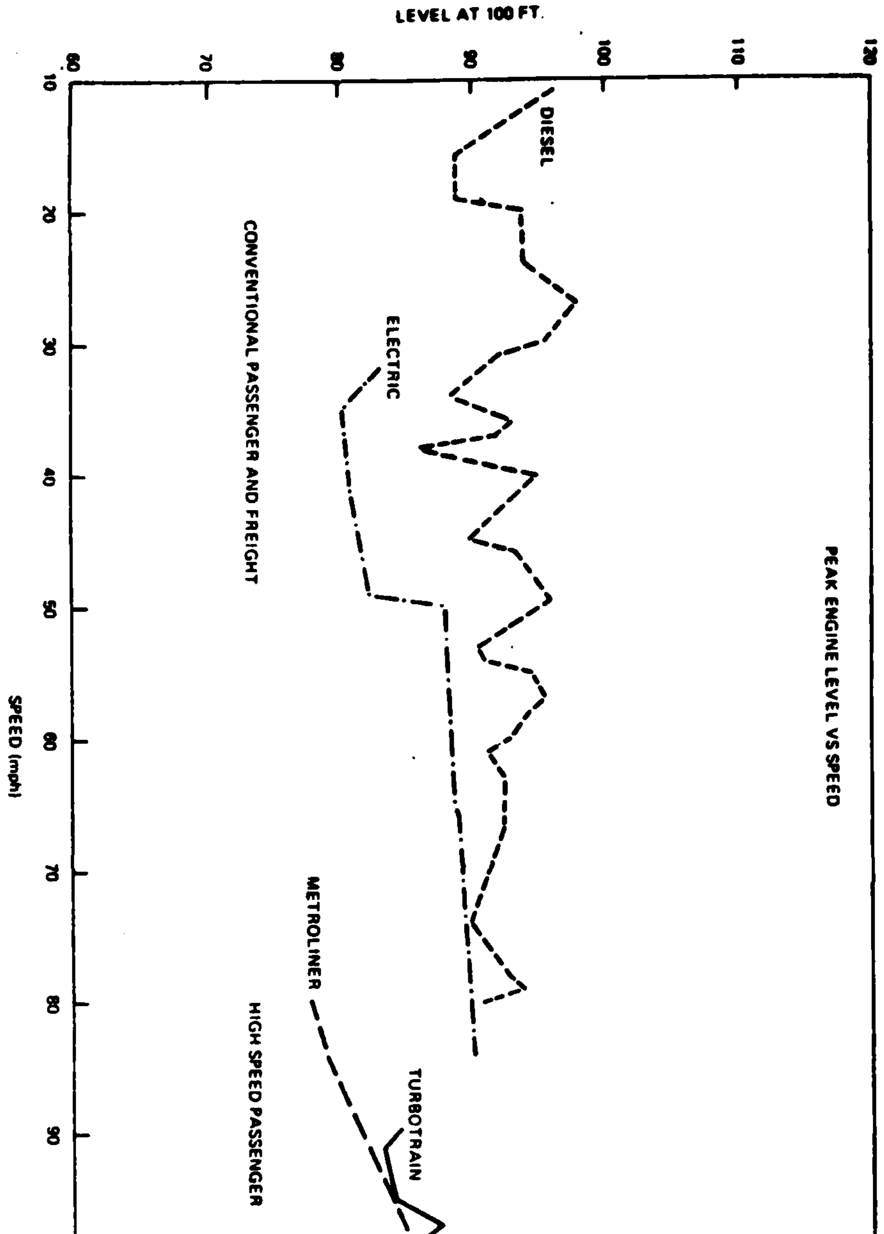


Figure 24. Peak Locomotive Noise Level vs. Speed

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Contro', Washington D.C., p. 4-19.

(d) Rail car noise consists of three sources of noise: (1) structural vibration and rattle, (2) refrigerator car cooling systems and (3) wheel/rail in-action. Of the three sources, wheel/rail interaction is by far the most significant. Typical measured levels of rail car noise are illustrated by Figures 25, 26, and 27. The relationship shown in Figure 26 indicates that wheel/rail interaction noise intensity increases at a rate of 30 log V where V is the train velocity. As an example, a train traveling at 60 mph (30 x 1.778 = 53.34dB(A)) will generate 9dB(A) more than a train operating at 30 mph (30 x 1.477 = 44.31dB(A)) from wheel/rail interaction. This relationship describes primarily the "roar" component of wheel/rail interaction. The higher levels as measured and illustrated in Figure 26 are indicative of the three other components of wheel/rail interaction which are: (1) flange rubbing, (2) flange squeal and (3) wheel impact.

5. Of all the existing modes of surface transportation, trains appear to be most variable in terms of the acoustical power produced. The effect that varying train lengths produce in the way of sound intensity levels is shown in Figure 28.[1] The wayside noise levels produced as shown in Figure 28 vary between 83-88dB(A) 25 feet away to 80-85dB(A) at 50 feet. These values appear to be relatively low for such proximate distances and are, in fact, presented only in the context of modern practices. Modern practices include such factors as: (1) welded rail which reduces noise levels on the average of 6dB compared to the past practice of bolted rails; (2) appropriate rail and wheel maintenance which accounts for a 5dB reduction and; (3) straight tracks or "tangential" tracks which hold flange squeal to a minimum.

[1]U.S. Department of Transportation; Transportation Noise and Its Control, U.S. Government Printing Office, Washington D.C., 1972, p. 17.

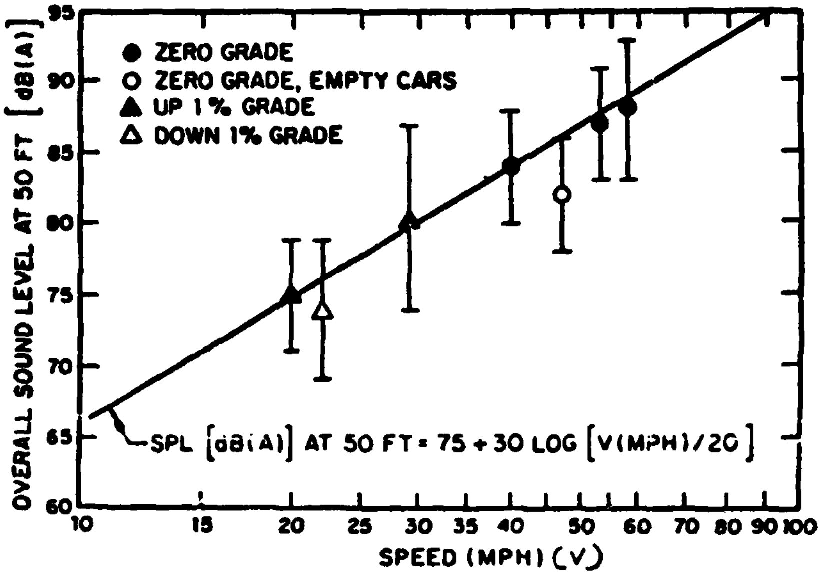


Figure 25. Wheel/Rail Noise Measured on Level Ground and on a 1% Grade

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Control, Washington, D.C., p. 4-28.

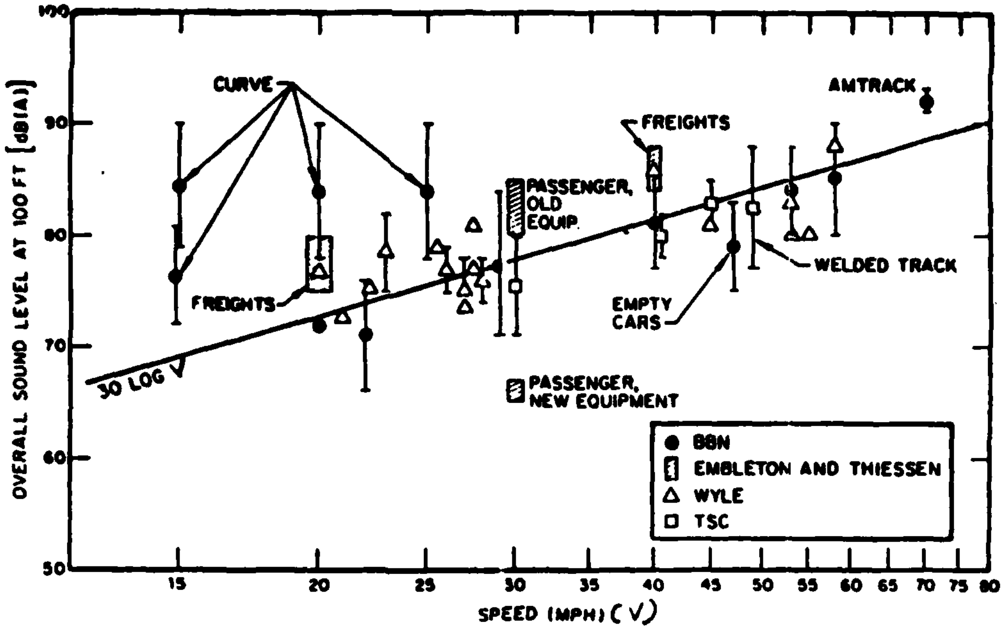


Figure 26. Measured Wheel/Rail Noise

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulations (1974), Office of Noise Abatement and Control, Washington D.C., p. 4-29.

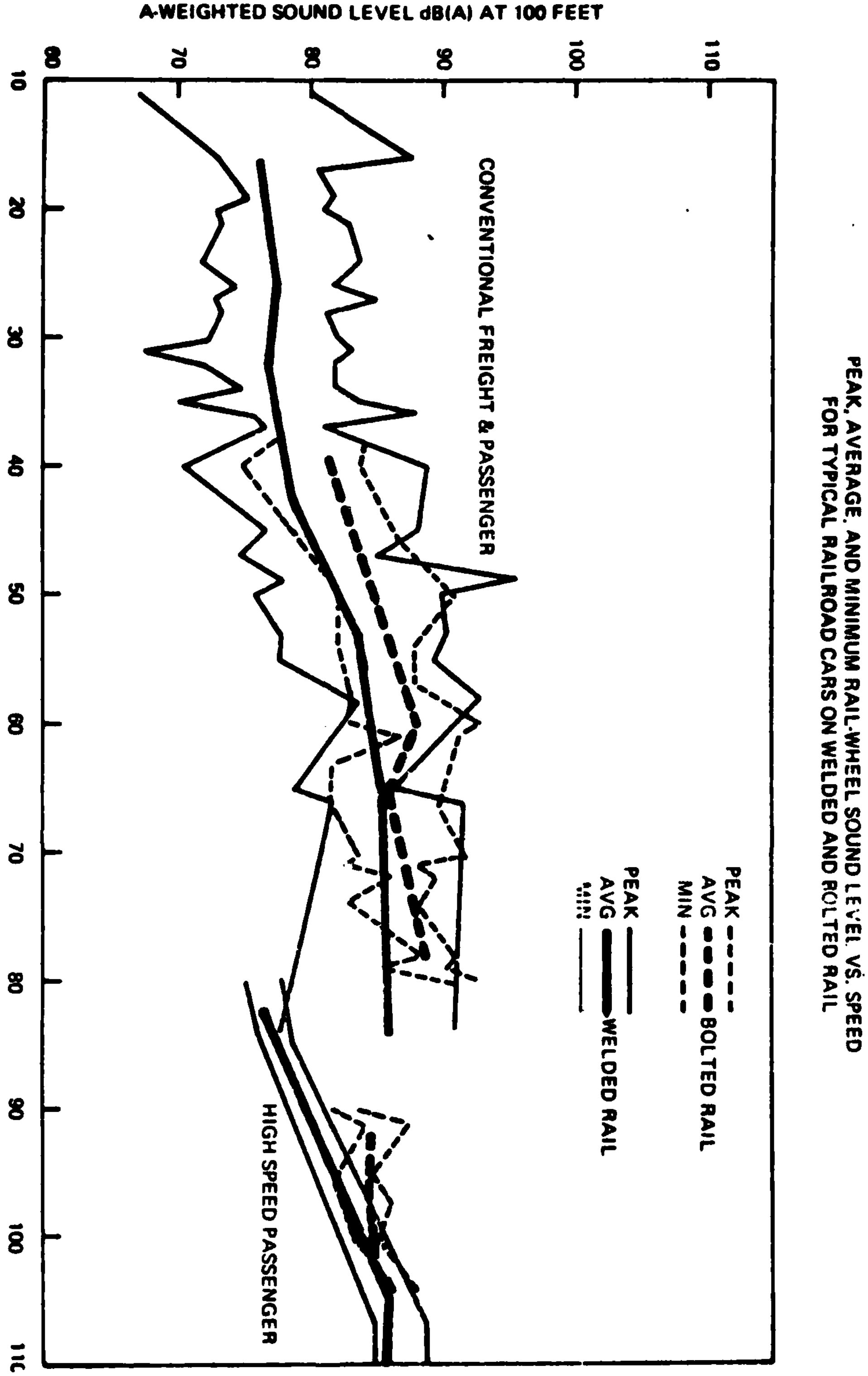


Figure 27. Average and Minimum Rail-Wheel Sound Level vs. Speed for Typical Railroad Cars on Welded and Bolted Rail

Source: Environmental Protection Agency, Background Document/Environmental Explanation for Proposed Interstate Rail Carrier Noise Emission Regulation (1974), Office of Noise Abatement and Control, Washington D.C., p. 4-30.

6. Unfortunately, most railroad companies presently practice a policy of "deferred maintenance" instead of preventive maintenance. As a result, track maintenance of the old type bolted rail sections is accomplished only when imperative to do so along with many other items which would reduce sound level intensities. Consequently, sound intensity levels generated by most local and area railroad operations can be expected to be 4-11dB(A) higher than those depicted in Figure 28 for corresponding distances.

7. Sound intensity levels taken of a local area freight train with a General Radio Type 1564-A sound analyzer at 25 feet yielded readings substantially higher than those depicted for an 8-car train in Figure 28. The readings recorded were of a 9-car train traveling at a speed of 30 miles per hour at three separate locations. The readings were 93, 94 and 93dB(A), respectively.[1]

D. Barge Noise

1. Surveys of noise in urban or rural settings have tended to concentrate on aircraft and highway noises, particularly the former. The investigation of noise levels and frequency spectra of surface modes of transportation other than highway sources have been less frequent. Barges, for all practical purposes, have been totally excluded in noise pollution surveys despite the fact that they rank among the top four modes of intercity freight transport. This exclusion can be accounted for by the simple explanation that they are neither as numerous or ubiquitous as the motor vehicle and not as numerous or proximate to the inhabitants

[1]Sound intensity levels were recorded under calm wind and normal lapse rate conditions, 15°F and 70% relative humidity along the Illinois Terminal Railroad tracks in Madison Co., Ill.

of urban areas as are trains. Barges, like trucks and trains, tend to generate noise as far as actual movement interaction is concerned, but do not produce levels nearly as high as the tire/pavement or wheel/track interactions produced by high speed trucks or trains.

2. The diesel engine power plants for barge towboats are similar to the engine power plants of trucks and trains and as such, are capable of radiating large amounts of acoustical power. The graphs depicted in Figure 24 show the frequency spectra for a truck according to the various components which contribute to a truck's overall noise level. The noise spectrum attributable to the engine and the exhaust are shown separately and an examination of the two spectra reveals that most of the sound intensity levels radiated are in the 125-250Hz range. The sum of the two noise spectra can be treated as an analogue for a diesel propelled towboat noise spectrum.[1]

3. Wayside noise levels emitted by towboats are not available. Noise level readings are available on board where interest centers on the noise levels the crewmen are subjected to during their operation routine. Noise surveys taken on board by the Occupational Safety and Health Agency (OSHA) aboard the M.V. Inez Andreas and the Margaret O. (Table 12). An analysis of Table 12 shows that the generators which are situated above the water line produce sound intensity levels in dB(A) almost as high as the diesel power plants, even at the higher revolution per minute settings. The reasons for this are that the frequency spectrum for the generator shows maximum output in the 500 to 1000Hz range, while at low r.p.m. settings,

[1] Personal communication with Mr. R.D. Lambdin, Federal Barge Lines, St. Louis.

the diesel engine show maximum output at 125 to 250Hz. At the higher r.p.m. settings shown in Table 12, the diesel power plant is emitting considerable noise energy at frequencies of more than 500Hz, but maximum sound intensity levels are still being generated in the 125-250Hz frequency range.

Table 12. Noise Level Readings in dB(A) and dB at Selected Points

	Margaret O			M.V. Inez Andreas		
	400RPM dB(A)dB	600RPM dB(A)dB	800RPM dB(A)dB	500RPM dB(A)dB	650RPM dB(A)dB	830RPM dB(A)dB
Aft Deck	78(88)	86(96)	88(98)	81(93)	-	94(104)
Generators	90(92)	92(94)	92(94)	100(103)	-	-
Lower Engine Room on C.L. between engines	91(94)	95(97)	98(100)	102(105)	-	-
Lower Engine Room 3'0" forward on C.L.	92(94)	95(98)	97(99)	101(104)	-	-
Forward Steering Room	72(82)	86(94)	94(100)	95(103)	-	105(112)

These readings were abstracted from noise level survey forms used by OSHA in determining on-board noise levels and acquired from Federal Barge Lines.

4. Botsford cites noise levels of 101-112dB(A) in the engine room of a river barge towboat and 94-98dB(A) in the steering room and shop (see Table 6, Section IV). These levels appear to agree with the range of readings taken aboard Federal Barge Lines' M.V. Inez Andreas at the corresponding locations.

5. If one uses 112dB(A) as maximum on-board output from the barge in order to project wayside noise levels at a 50-foot distance, the following factors would apply:

(a) A geometric attenuation of 17-24dB (based on readings on board taken at 3 to 5 feet from the source of sound as shown on Table 12).

(b) The hull of the towboat consists of an A-36 steel plate outboard hull 3/8 inch to 1/2 inch thick and a vertical wing bulkhead plate varying between 1/4 to 3/8 inches that separates the engine room from the hull. The barrier effect of the bulkhead and hull will result in an additional 14-17dB attenuation.

(c) Based on the above factors, projected wayside sound intensity levels at 50 feet would fall within a range of 71 to 81dB(A) based only on the attenuation of the inverse square law and the barrier effect of the hull.

6. Readings taken with the General Radio Type 1564-A sound analyzer appear to agree with the theoretical attenuation that should occur at a 50-foot distance. Sound intensity levels were recorded of passing barge craft at distances of 50 and 200 feet as shown in Table 13. The most surprising fact concerning the readings recorded in Table 13 is the intensity of the sound levels produced by the bow of the barge as it approaches a wayside position. At 50 feet the barge/water interaction

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in this report.)

Table 13. Measured Barge Wayside Noise Levels (dB)[1]

	Distance from Barge	Barge/Water Interaction Noise Front	Barge/Water Interaction Noise Side	Towboat Wayside Noise
#1	50 feet	78	70	81
#2	50 feet	76	69	80
#3	200 feet	70	62	71
#4	200 feet	69	61	71

[1]Temperature 7°F @ 1810 hours, 2/9/75
Relative Humidity 78%
Ground Level Temp. Inversion up to 400'

was 78 and 76dB, while at 200 feet it was 64 and 70dB. Barge/water interaction levels are considerably lower once the bow of the barge passes the observer's wayside position (70 and 69dB at 50 feet). While the sound intensity levels of the passing towboat produced 81 and 80dB at 50 feet, frequency spectrum analysis showed that much of the output was in the 500 to 1,000Hz range indicating that the generators were accounting for a major portion of the sound intensity levels. The water appears to muffle a substantial portion of the sound intensity levels produced by the diesel power plant because of their position with respect to the water line on the outside hull. For this reason, a conversion of only a negative two (2) factor appears warranted because of the noise output at frequencies well above the 125-250Hz range. The decibel (dB) readings in Table 13 can be converted to corresponding dB(A) levels by adding the negative two (2) conversion factor.

7. It should be pointed out that the sound analyzer readings shown in Table 9 were taken at dusk under calm wind and a reverse lapse rate condition. The 50-foot readings were taken at the water's edge so that maximum reflection of the sound waves was occurring. It is assumed, for these reasons, that the sound intensity levels in dB recorded on the sound analyzer were somewhat higher than they would be during day time hours. The readings taken at 200 feet show the effects of the reverse lapse rate even though part of the terrain from 50 to 200 feet was grass covered. Based on geometrical attenuation alone, assuming a 112dB output of sound on board, the 200 foot readings should have been somewhat lower than shown for the number 3 and 4 readings in Table 13 (68, 60 and 69dB, respectively).

SUMMARY

Transportation noises are the major source of noise in urban environs accounting for three-fourths of the noise levels urban dwellers experience. Trucks, particularly diesel trucks, are a major source of highway generated noise causing noise levels to exceed the 85-90dB(A) range frequently at wayside distances of 50 feet and less. These noise levels are common on inner city as well as suburban expressways as a result of tire/pavement interaction at speeds in excess of 50 miles per hour. Truck noises can constitute a very intrusive noise problem when operating at night because of lower urban background levels.

Railroad noises, in urban areas, not only come from pass-bys on the right-of-ways, but from switchyards where diesels are running on a 24-hour basis. Noise levels stemming from rail rolling stock can be highly variable (as indicated in Section III, C) depending on how old the rolling stock is, the condition of the railroad tracks and the number of rail cars being pulled by the diesel locomotive. Railroad noises tend to attenuate over a distance more slowly than truck noises or barges because of their length which makes them generate noise as an ideal line source rather than as a point source.

A direct comparison of noise levels of trucks and trains and the associated impacts is not feasible except in a most general way because dB levels radiated by both modes of transport are quite variable. Noise levels from highways and streets hold fairly constant and thus do not make the same impression as the less frequent noises from freight trains. Only when the automobile-truck mix on highways shifts towards a 20 percent or

higher truck mix do the highway noise levels begin to produce an annoyance reaction similar to that produced by trains in urban areas proximate to residential districts (see Section IV). G.J. Thiessen (Community Noise Levels) points out that most communities are aware of the role of trucks in noise pollution and that the perceived role is certainly negative. He cites the fact that in Ottawa, Canada, heavy trucks constitute about five percent of all vehicles, but contribute more noise than all the rest of the vehicles put together as perceived by citizens of Ottawa. Botsford (Damage Risk) notes that practically all public transportation modes produce noise levels that exceed 90dB(A) on an intermittent basis, but none of the public transportation modes are as numerous or ubiquitous as the heavy tractor-trailer trucks.

As mentioned in Section III, C, literature concerning the role of barges in noise pollution is essentially lacking. The very fact that literature does not exist concerning the role of noise pollution of the nation's river and introcoastal waterway barges is testimony to the barges' inocuous status. There are several reasons for this, some of which are obvious: (1) barges, when compared to trucks and even trains are not as numerous; (2) most urban residential areas are located substantial distances from river docking and fueling facilities; barges are rarely, if ever, noticed from the standpoint of producing annoying noise levels; (3) barges are much slower than either trucks or trains and consequently do not generate the high dB levels from interaction with the water surfaces that trucks or trains produce in interaction with pavement or steel tracks; (4) because rivers develop bluffs along miles of shoreline, natural sound barriers exist in urban areas as well as in rural areas which significantly attenuate the noise produced by the barge; (5) the noise produced by the tow-boat engines are partially muffled by the river as heard by a wayside observer due to the water level on the outside hull being higher than some towboat's powerplant; (6) compared to the highway or railroad tracks where an observer can get as close as 15 feet or less, the average distance of the barge channel from the shoreline may be 450 feet or more on the open river stretches;[1] (7) the sound propagated by the towboat once it reaches a shoreline position is affected by a vegetative cover that is, in general, more lush than in the case for highways (if not railroads) in rural and urban areas; (8) at night when propagation of sound over land is intensified by reverse lapse rates, propagation loss over the river tends to take place in much the same manner as it did in the daytime hours - in other words, the river water does not cool down as does the adjacent land surface and a normal lapse rate over the river tends to prevail into the night-time hours causing a more rapid attenuation rate of noise than over land (see Section II, 6).

At distances of 50 feet, the maximum noise levels to be experienced from a passing barge appear to be in the 78-81dB range. This was the range recorded at that distance on the Chain of Rocks canal and the range predicted by mathematical projections. Equivalent dB(A) readings would be in the 76-79dB(A) range. This range compares favorably with truck traffic. This range is approximately the same as a slow moving freight train at a 50-foot distance and is considerably less than a commuter

[1]This is the average distance of the barge channel from the shoreline on the Mississippi River according to personal communications with Mr. Lambdinm Federal Barge Lines, St. Louis.

train. In most cases, however, the impact of noise produced by a passing barge will be much less than the 76-79dB(A) range at 50 feet. The most proximate distance, normally of individuals in an urban or rural setting experiencing barge noise will be well over 450 feet. As shown in the Appendix, noise levels at 450 feet will be no more than 60dB(A) under daytime conditions, perhaps as much as 65dB(A) at night. These noise levels are substantially less than those generated by freeway traffic or railroad sources at 450 feet and more proximate distances owing to the more rapid attenuation of barge generated noise as a point source. Barge generated noises at distances of 450 feet or more do not rank as intrusive and compare with noise levels generated by automobiles on a lightly used city street or rural road.

APPENDIX

A. Projected Propagation Losses of Sound

As discussed in Section II, there are six factors affecting propagation of sound over distance. The magnitude of propagation losses over distances ranging from 50 to 2000 feet is shown in Table A-1 according to the manner in which these six variable factors affect sound propagation. From Table A-1 it is possible to estimate sound levels in varying environments from point sources of sound.

The major factor accounting for decrease in sound intensity levels is independently depicted in Figure A-1. The two lower curvilinear plots in Figure A-1 (a 100dB intensity measured at 10 feet and a 98dB measured at 5 feet) show how sound propagation losses occur over distance recording to the inverse square law for point sources. The uppermost plot reveals how noise is attenuated from a line source (measured 100dB at 10 feet) according to the inverse square law.

The magnitude of propagation loss caused by barriers of varying height at various distances from the point source of sound is shown in Table A-2. Noise reduction values were calculated for frequencies of 63 through 1000 Hz only because nearly all sound radiated by the barge and the towboat's power-plant and generators is at frequencies of 600Hz and less. Calculations of the barrier noise reduction effect for higher frequencies would result in more propagation losses than shown for the frequencies in Table A-2. The values in Table A-2 were calculated from the formula shown in Tables 3 and F-1, assuming an air temperature of 59°F and a receiver location completely within the sound shadow angle, but at a distance of unity behind the barrier.

TABLE A-1 Projected Propagation Losses* (in decibels) Due to Factors Listed in Section II over Distances of 50 feet to 2000 feet[a]

Distance from Sound Source (feet)	(1) Loss due to geometric attenuation[b]	(2) Loss due to atmospheric attenuation[c]	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
			Loss due to barrier effect (Utilizing various heights of Mississippi River bluffs as natural barriers[d])							Loss due to vegetative cover[e]			Loss or gain due to varying atmospheric lapse rates[f]				Loss due to wind structure[g]		
			15 feet	30 feet	45 feet	60 feet	100 feet	270 feet	570 feet	Bare, smooth ground surface	Short to medium grass cover	Tall grass, lush cover	Steep normal lapse rate	Shallow normal lapse rate	Isothermal lapse rate	Reverse lapse rate	Upwind Direction	Crosswind Direction	Downwind Direction
50	17.5	0	0.6	2.6	5.8	9.4	20	75	185	0	9.5	10.2	≤4	0 to 1	0	0 to gain of 1 dB	1 to 2	0 to 1	-1 to 1
100	23.6	0	0.4	1.5	3.2	5.6	14	63	160	0	12.7	13.7	≤4	1	0	gain of 1 dB	1 to 2	0 to 2	-1 to 1
150	27.1	0	0.2	1.0	2.2	3.8	10	53	147	0	14.6	15.7	4-5	1 to 2	0	gain of 1 to 2 dB	1 to 2	1 to 2	0 to 1
300	33.2	0	0.1	0.5	1.1	2.0	5.4	35	115	0	17.9	19.3	5-6	1 to 2	0	gain of 2 to 3 dB	2 to 3	1 to 3	0 to 1
450	36.7	1	0.1	0.3	0.8	1.3	3.7	25	92	0	19.8	21.3	6-7	1 to 3	0	gain of 2 to 4 dB	2 to 4	1 to 4	0 to 2
500	37.6	1	0.1	0.3	0.7	1.2	3.3	23	87	0	20.3	21.8	6-8	1 to 4	0	gain of 2 to 5 dB	3 to 5	1 to 4	0 to 2
1000	43.6	2	0	0.2	0.4	0.6	1.7	12	51	0	23.5	25.3	6-10	2 to 4	0	gain of 3 to 6 dB	5 to 8	2 to 4	1 to 2
2000	49.6	3	0	0.1	0.2	0.3	0.6	6.1	26.5	0	26.7	28.8	10+	4+	0	gain of 6+ dB	8+	4+	2+

*-based on the inverse square law (see Figure A-1) for point sources of sound measured at a 5 foot distance

a-450 feet is the average distance barge craft will be from the shoreline on open Mississippi River stretches

b-includes a reflectance factor of a plus 2.4 dB for sound radiated initially over an essentially smooth surface (the river) as shown in Section II,B,1(b)

c-assuming a frequency of less than 1000 Hz and interpolating from Figure 7, Section II, as per British Aircraft Corporation study

d-calculations based on a 125 Hz frequency radiated by passing towboat, an ambient air temperature of 59°F, and the observer's location being situated completely within the shadow angle (higher frequencies would result in more noise reduction, while lower frequencies would result in less noise reduction)

e-calculations consist of a 0.54 percent and 0.58 percent additional propagation loss for short grass and lush vegetative cover respectively for the corresponding distances shown in Table A-1 (see Table 4 in Section II)

f-these values are <u>estimations</u> only based on interpreting and comparing Figures 10(a), 10(b), and 10(c) with Figure 11

g-these values are <u>estimations</u> only based on interpreting and comparing Figures 13(a) and 13(b) with Figure 11

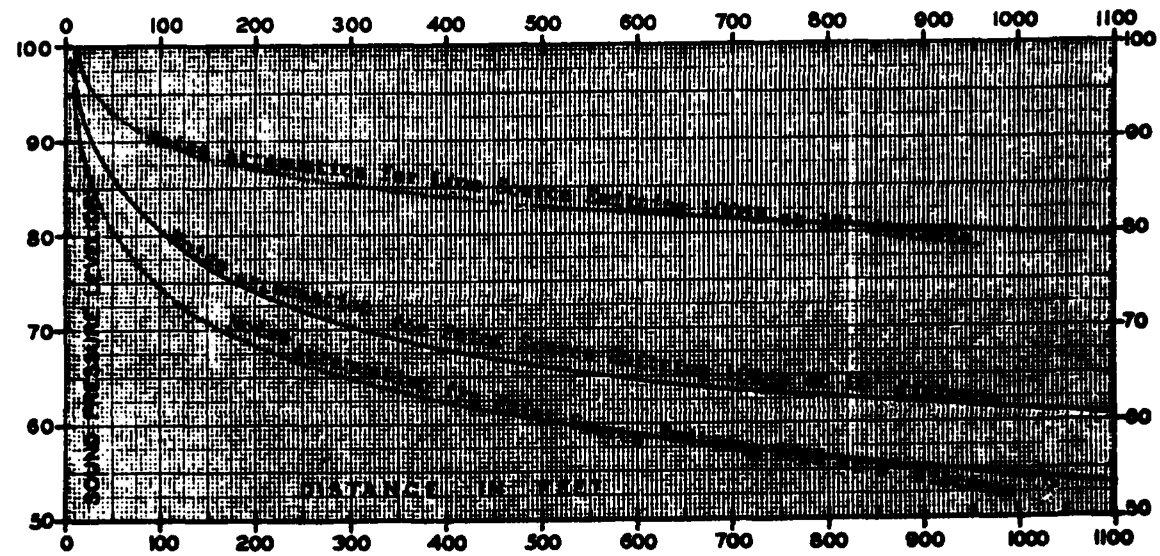


Figure A-1. Noise reduction with distance due to inverse-square law

TABLE A-2

Noise Reduction due to Barrier Height at varying distances (in dB)

Barrier (ft) Height	Source Distance	Receiver Distance	Frequency (Hz) 63	125	250	500	1000
15	15	1	1.0	2.0	4.0	8.0	16.0
15	25	1	.7	1.4	2.8	5.6	11.2
15	50	1	.3	.6	.9	1.8	3.6
15	100	1	.2	.4	.8	1.6	3.2
15	150	1	.1	.2	.4	.8	1.6
15	300	1	.063	.126	.252	.504	1.008
15	450	1	.041	.082	.174	.348	.696
15	500	1	.037	.074	.148	.296	.592
15	1000	1	.018	.036	.072	.144	.288
15	2000	1	.099	.018	.036	.072	.144
30	15	1	3.1	6.2	12.4	24.8	49.6
30	25	1	2.4	4.8	9.6	19.2	38.4
30	50	1	1.3	2.6	5.2	10.4	20.8
30	100	1	.74	1.48	2.96	5.92	11.84
30	150	1	.50	1.00	2.00	4.00	8.00
30	300	1	.24	.48	.96	1.92	3.96
30	450	1	.17	.34	.68	1.36	2.72
30	500	1	.150	.300	.600	1.200	2.400
30	1000	1	.076	.152	.304	.608	1.216
30	2000	1	.039	.078	.166	.332	.664
45	15	1	5.5	11.0	22.0	44.0	88.0
45	25	1	4.5	9.0	18.0	36.0	72.0
45	50	1	2.9	5.8	11.6	22.2	44.4
45	100	1	1.62	3.24	6.48	12.96	25.92
45	150	1	1.11	2.22	4.44	8.88	17.76
45	300	1	.56	1.12	2.24	4.48	8.96
45	450	1	.38	.76	1.52	3.02	6.04
45	500	1	.36	.72	1.44	2.88	5.76
45	1000	1	.18	.36	.72	1.44	2.88
45	2000	1	.09	.18	.36	.72	1.44
60	15	1	7.8	15.6	31.2	64.4	128.8
60	25	1	6.6	13.2	26.4	52.8	105.6
60	50	1	4.7	9.4	18.8	37.6	75.2
60	100	1	2.8	5.6	11.2	22.4	44.8
60	150	1	1.9	3.8	7.6	15.2	30.4
60	300	1	.98	1.96	3.92	7.86	15.72
60	450	1	.66	1.32	2.64	5.38	10.76
60	500	1	.60	1.20	2.40	4.80	9.60
60	1000	1	.30	.60	1.20	2.40	4.80
60	2000	1	.14	.36	.72	1.44	2.88

TABLE A-2 (Continued)

Barrier (ft) Height	Source Distance	Receiver Distance	Frequency (Hz) 63	125	250	500	1000
75	15	1	10.3	20.6	41.2	82.4	164.8
75	25	1	9.7	19.4	38.8	77.6	155.2
75	50	1	6.7	13.4	26.8	53.6	107.2
75	100	1	4.1	8.2	16.4	32.8	65.6
75	150	1	2.97	5.94	11.88	23.76	47.52
75	300	1	1.55	3.10	6.20	12.40	24.80
75	450	1	1.04	2.08	4.16	8.32	16.64
75	500	1	.85	1.70	3.40	6.80	13.60
75	1000	1	.43	.86	1.72	3.44	6.88
75	2000	1	.22	.44	.88	1.76	3.52
100	15	1	14.4	28.8	57.6	105.2	210.4
100	25	1	13.1	26.2	52.4	104.8	209.6
100	50	1	10.3	20.6	41.2	82.4	164.8
100	100	1	7.0	14.0	28.0	56.0	112.0
100	150	1	5.07	10.14	20.28	40.56	81.12
100	300	1	2.72	5.44	10.88	21.76	43.52
100	450	1	1.84	3.68	7.36	14.72	29.44
100	500	1	1.66	3.32	6.64	13.28	26.56
100	1000	1	.84	1.68	3.36	6.72	13.44
100	2000	1	.42	.84	1.68	3.36	6.72
270	15	1	42.8	85.6	171.2	342,4	684.8
270	25	1	41.2	82.4	164.4	328.8	656.6
270	50	1	37.6	75.2	150.4	300.8	601.6
270	100	1	31.5	63.0	126.0	252.0	304.0
270	150	1	26.6	53.2	106.4	212.8	425.6
270	300	1	17.4	34.8	69.6	139.2	278.4
270	450	1	12.5	25.0	50.0	100.0	200.0
270	500	1	11.4	22.8	45.6	91.2	181.4
270	1000	1	6.0	12.0	24.0	48.0	96.0
270	2000	1	3.0	6.0	12.0	24.0	48.0
570	15	1	93.0	186.0	372.0	744.0	1488.0
570	25	1	90.7	181.4	362.8	725.6	1451.2
570	50	1	87.5	175.0	350.0	700.0	1400.0
570	100	1	80.2	160.4	320.8	641.6	1283.6
570	150	1	73.6	147.2	294.4	588.8	1177.6
570	300	1	57.6	115.2	230.4	460.8	921.8
570	450	1	46.3	92.4	184.8	369.6	739.2
570	500	1	43.6	87.2	174.2	348.4	696.8
570	1000	1	25.3	50.6	101.2	202.4	404.8
570	2000	1	13.4	26.8	53.6	107.2	214.2

B. Projected Barge & Towboat Sound Intensity Levels

A vicinity of projected noise levels can be made from Table A-1 according to a set of specific conditions. Consider the following set of conditions:

1) a passing towboat and barge measured at 98dB at a 5 foot wayside position;

2) observer located on the immediate shoreline at a 450 foot wayside position;

3) a typical steep normal lapse rate condition in the early summer during mid-afternoon hours;

4) a cross-wind

This would result in a sound intensity level of 98dB-36.7 (geometric attenuation) - 1dB (atmospheric attenuation) - 6dB (steep normal lapse rate refraction) - 1dB (reduction due to crosswind) or 53.3dB

If the following condition was added to the aforementioned set:

1) a distance of 50 feet from the shoreline characterized by a lush vegetative surface (which typically exists along the Mississippi River); then the sound intensity level would be 53.3 - 0.9dB (geometric attenuation from 450 to 500 feet) - 0.5dB (the difference between 21.8 and 21.3dB under column 12 of Table A-1) or 51.9dB.

Noise reduction due to a bluff position along the Mississippi River could be added by assuming the above conditions as well as a bluff height of 45 feet above the river elevation: the sound intensity level now becomes 51.9dB - 0.8dB (shown in column 5 of Table A-1) or 51.1dB.

Sound intensity levels, likewise, can be caluclated from Table A-1 for the following set of conditions:

1) a passing towboat and barge radiating 98dB at a 5 foot wayside position

2) distance of 150 feet from the shoreline to the barge;

3) observer's position on short to medium grass covered surface 150 feet from the shoreline for a total distance of 300 feet

4) a typical nightime inversion;

5) a light wind blowing in a downward direction.

The sound intensity level would be 98 - 33.2 (from column 1 opposite 300 feet) - 3.3 (the difference between 17.9 & 14.6 under column 11 opposite 300 & 150 feet respectively) + 3.0 (column 16 opposite 300 feet) - 0 (column 19 opposite 300 feet) or 64.5dB.

It should be pointed out that the variables listed in Table A-1 can be treated in an additive manner as long as the elevations of the sound source and the receiver are approximately the same, without the presence of a barrier. If a barrier exists, however, between the source and the receiver, then the other variables listed in Rable A-1 to the right of the barrier effect columns will vary increasingly from an additive relationship as the barrier sound shadow angle increases. In cases where the sound shadow angle approaches 10 degrees, conservative projections should be used by adding only losses due to atmospheric attenuation and barrier noise reduction effect to the attenuation caused by the inverse square principle. To illustrate:

1) a barge radiating 98dB at a 5 foot wayside position;

2) an observer's position on a 100 foot high bluff 150 feet from the passing barge;

3) a shallow normal lapse rate and a wind blowing from an upwind direction

The sound intensity level would be 92 - 27.1 (column 1 opposite 150 feet) - 0 (column 2 opposite 150 feet) - 10 (column 7 opposite 100 feet) or 60.9dB.

C. Projections of Sound Intensity Levels from Sources other than Barges.

The top curvilinear plot in Figure A-1 shows how attenuation due to the inverse square low proceeds from a line source such as a freight train or a highway characterized by a moderate to heavy flow of traffic. Propagation loss of sound energy for live sources of sound over distances of 50 to 2000 feet is shown below in Table C-1.

Table C-1

Propagation Loss Due To Geometric Attenuation From
A Line Source Of Sound (in decibels)*

		50 ft	100 ft	150 ft	300 ft	450 ft	500 ft	1000 ft	2000 ft
Geometric Attenuation Loss		10	13	14.8	17.8	19.5	20	23	26
Propagation Loss due to Vegetative Cover	(short grass cover)	15.4	20.0	22.8	27.4	30.3	30.8	35.4	40.0
	(Tall, lush grass cover)	15.8	20.6	23.4	28.1	30.8	31.6	36.3	41.1

* assuming no ground reflectance factor for a ground level wayside noise at 5 feet

By using the appropriate values in Table C-1 in place of column 1 and column 10-12 in Table A-1, the rest of the columns can be used in projecting sound levels from alternative modes of transport. To illustrate, consider the the following:

1) a train radiating 98dB at a 5 foot wayside position;

2) an observer on a lush vegetative ground surface 450 feet away from the passing train;

3) a summer day in the mid-afternoon hours (steep lapse rate);

4) a cross-wind.

The sound intensity level would be 98 - 30.8 (from Table C-1) - 6 (from column 13 of Table A-1) - 1 (from column 18 of Table A-1) or 60.2dB. This can be compared, subsequently, to the 53.3dB level produced by the barge under the same set of conditions as discussed in the first example in section B of the appendix.

D. On-board Barge Noise Levels

An OSHA noise survey is shown in Table D-1 for the "Margaret O." and the M.V. Inez Andreas barge craft. Sound level readings are given at various locations in dB(A), dB(B), and dB(C) weightings: The dB(C) weighting most closely approximates conventional dB sound intensity levels. The readings on board were taken at distances varying from 3-5 feet from the power plant units depending on the location and are susally specified where appropriate. It should be noted that most of the on-board db(C) readings are well below the 112dB wayside noise level at 5 feet used to make projections in the text and in section A of the appendix (before hull and bulkhead attenuation of 14dB was applied).

E. Statistical Distributions for Highway and Street Generated Noise Levels

Statistical distribution of automobile, motorcycle and heavy trucks ($\geq$24,000 lbs or $\geq$ 3 axles) noise levels are shown in Figures D-1 through D-5*. It is noteworthy to mention that at 50 feet 50 percent of the heavy trucks were producing levels of 87dB(A) or more at 55 miles per hour (Figure E-2). By way of comparison only 0.1 percent automobiles produced this noise level at 70 miles per hour (Figure E-1). Bus and motorcycle noise levels (at highway speeds) of 87db(A) or greater are exceeded only by 5 and 4 percent of these modes of transport.

* Illinois EnvironmentalProtection Agency, 1974 Illinois Motor Vehicle Noise Survey, Paper presented at 88th Meeting of the Acoustical Society of America, St. Louis, Mo., 1974.

TABLE D-1

Sound Level Survey Aboard M. V. Inez Andreas
TB838 Boat #2, During Bank Test, Inside Boat, 7200 HP
May 15, 1974

	@ 500 RPM Sound Level			@ 650 RPM Sound Level			@830 RPM Sound Level		
	A	B	C	A	B	C	A	B	C
Lower Engine Room									
3'-0 Fwd of Main Engine	101	102	104						
Between Engines (STBD)	102	105	105						
Between Engines (Port)	102	104	105						
At C_L Gear Box	100	102	104						
Upper Engine Room									
3'-0 Fwd of Control Booth	98	100	102	102	103	104	103	105	106
3'-0 to Port of Booth	97	98	101	100	101	103	101	103	106
3'-0 to Stbd of Booth	96	98	100	99	101	102	101	103	105
Inside Control Booth (Door Open)	85	86	91						
*Inside Control Booth (Door Closed)	76	82	86	77	84	93	83	88	95
Meter on Floor Facing Door	81								
Gen. Room Aft of Control Booth	93	96	97						
Gen. Room 1'-0 from Gen. Exh.	100	101	103						
Steering Room (Fwd)	95	99	103				105	108	112
Galley	65	73	82						
Outside Deck @ Aft Strg Rm Bhd	81	88	93				94	98	104
Btwn Strg & Flkg Rudders							107	112	115
Inside Hull Between Rudders							117		
Aft Crew Qtrs Port Side				68	77	84			

* Control booth had an untreated opening to upper deck. No provisions were made to dampen noise transmission thru floor. Door was a hollow core door with an aluminum and vinyl rubber threshold.

TABLE D-1 (Continued)

Sound Level Survey Aboard M/V "Margaret O", TB856
By: Eversmeyer - Date: 11-8-74
63 dB dial setting, 1800 HP

	Prop 100 Eng 400 RPM			Prop 150 Eng 600 RPM			Prop 200 Eng 800 RPM		
	A	B	C	A	B	C	A	B	C
Pilot House	43	55	68	52	66	74	59	71	82
Aft Deck	78	82	88	86	90	96	88	94	98
Generators	90	91	92	92	93	94	92	93	94
Lower Engine Room									
3'-0" forward of Engines on C_L	91	93	94	95	96	97	98	99	100
Between Engines @ C_L	92	94	94	95	96	98	97	98	99
Between Gear Boxes	92	93	94	95	96	98	99	101	102
Machinery Space	80	82	83	84	86	87	85	87	89
Upper Engine Room									
*Control Booth	64	72	81	68	75	83	69	76	86
*Control Booth dbA 125	66	73	81	69	76	84	70	77	84
*Control Booth dbB 250	66	72	82	69	75	84	72	78	87
*Control Booth dbC 500	65	71	82	69	75	85	73	78	86
*3'-0" Forward of Control Booth	87	89	91	90	91	94	91	93	95
*3'-0" to Port of Control Booth	84	85	90	81	89	92	88	90	94
*3'-0" to Starboard of Control Booth	90	92	93	90	91	94	91	92	94
*Inside Control Booth Door Closed	64	72	81	68	76	83	69	76	86
*Inside Control Booth Door Open	79	81	83	72	74	77	79	83	87
*Meter on Floor Facing Closed Door	80	81	84	70	78	84	74	80	86
*Meter Facing Air Conditioner	-	-	-	-	-	-	-	-	-
Steering Room	72	77	82	86	91	94	94	97	100
Engineer's Room	62	70	75	65	71	75	66	73	76
Galley	63	66	70	66	72	76	68	74	77

* Taken on Up-River Run

Sound Level Survey Aboard M. V. Inez Andreas
TB838 #2, May 15, 1974

Conditions: 3 main engines operating at RPM noted
Continuous operation of one generator engine

	A level	B level	C level
Engines Idle at Dock			
3'-0 Fwd of C_L Engine	93	95	96
At Stair Platform (Eng Rm)	96	97	98
P. House (Door Open)	55	64	71
P. House (Door Closed)	50	58	68
Travel Upstream (RPM Unknown)			
3'-0 Fwd of Control Booth	98	99	103
Inside Control Booth @ Stand	75	79	85

FIGURE E-1 STATISTICAL DISTRIBUTIONS OF AUTOMOBILE SOUND LEVELS DURING HIGH SPEED CRUISE ON FREEWAYS: 1973 SPEED LIMIT 70 MILES PER HOUR, 1974 SPEED LIMIT 55 MILES PER HOUR

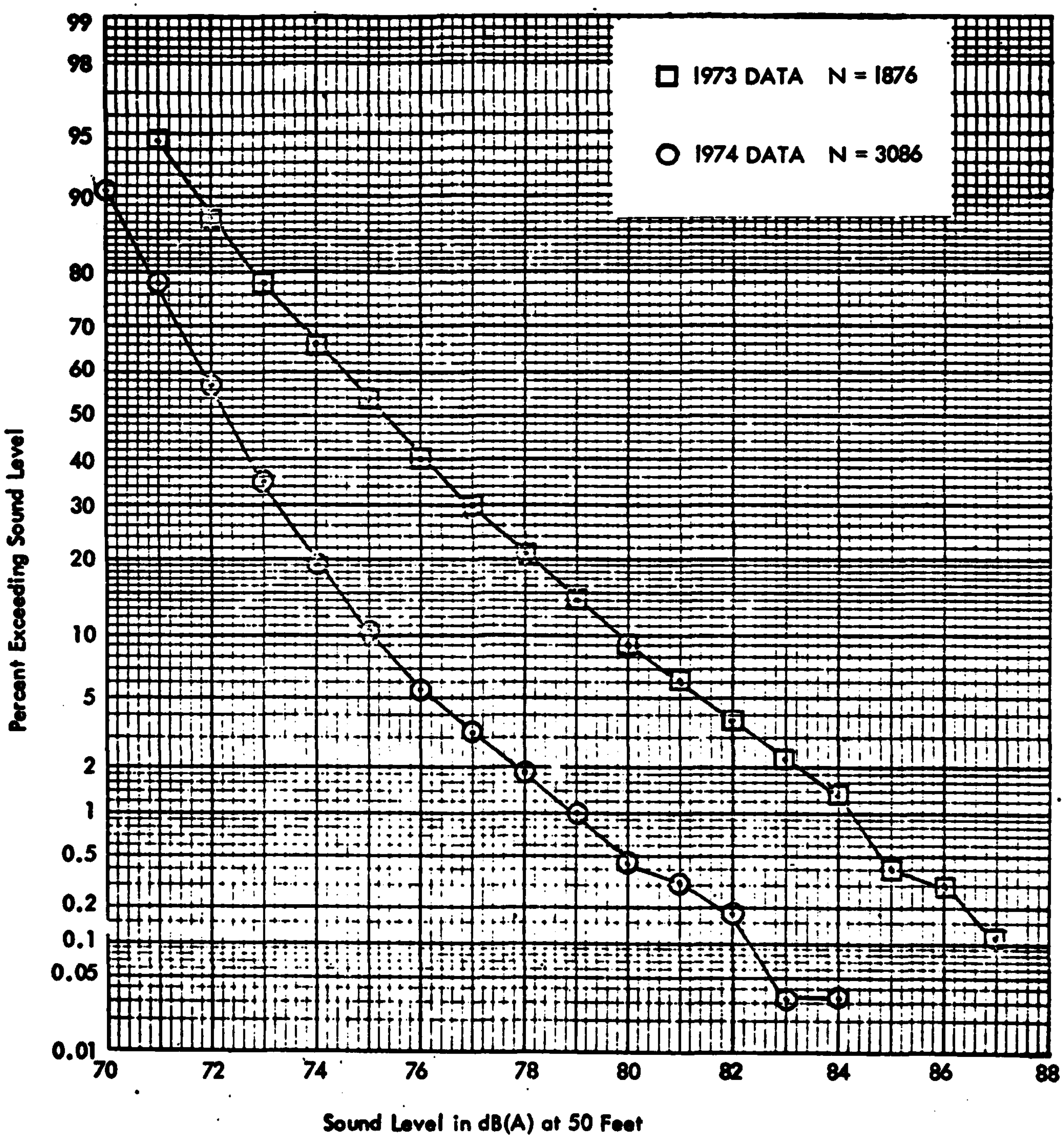


FIGURE E-2 **STATISTICAL DISTRIBUTION OF HEAVY TRUCK SOUND LEVELS DURING HIGH SPEED CRUISE ON FREEWAYS: SPEED LIMIT 55 MILES PER HOUR**

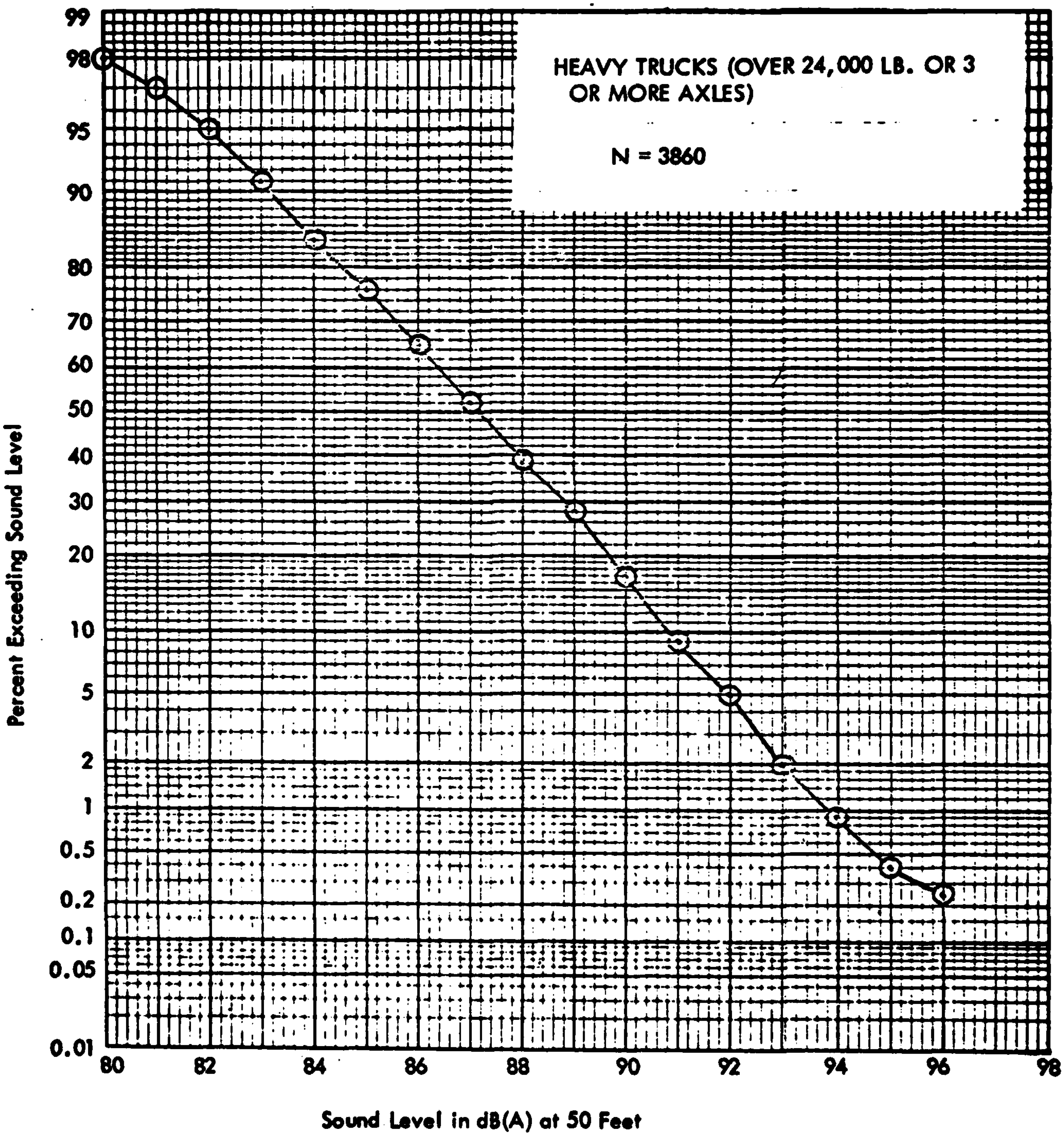


FIGURE E-3 STATISTICAL DISTRIBUTIONS OF MOTORCYCLE AND BUS SOUND LEVELS DURING HIGH SPEED CRUISE ON FREEWAYS: SPEED LIMIT 55 MILES PER HOUR

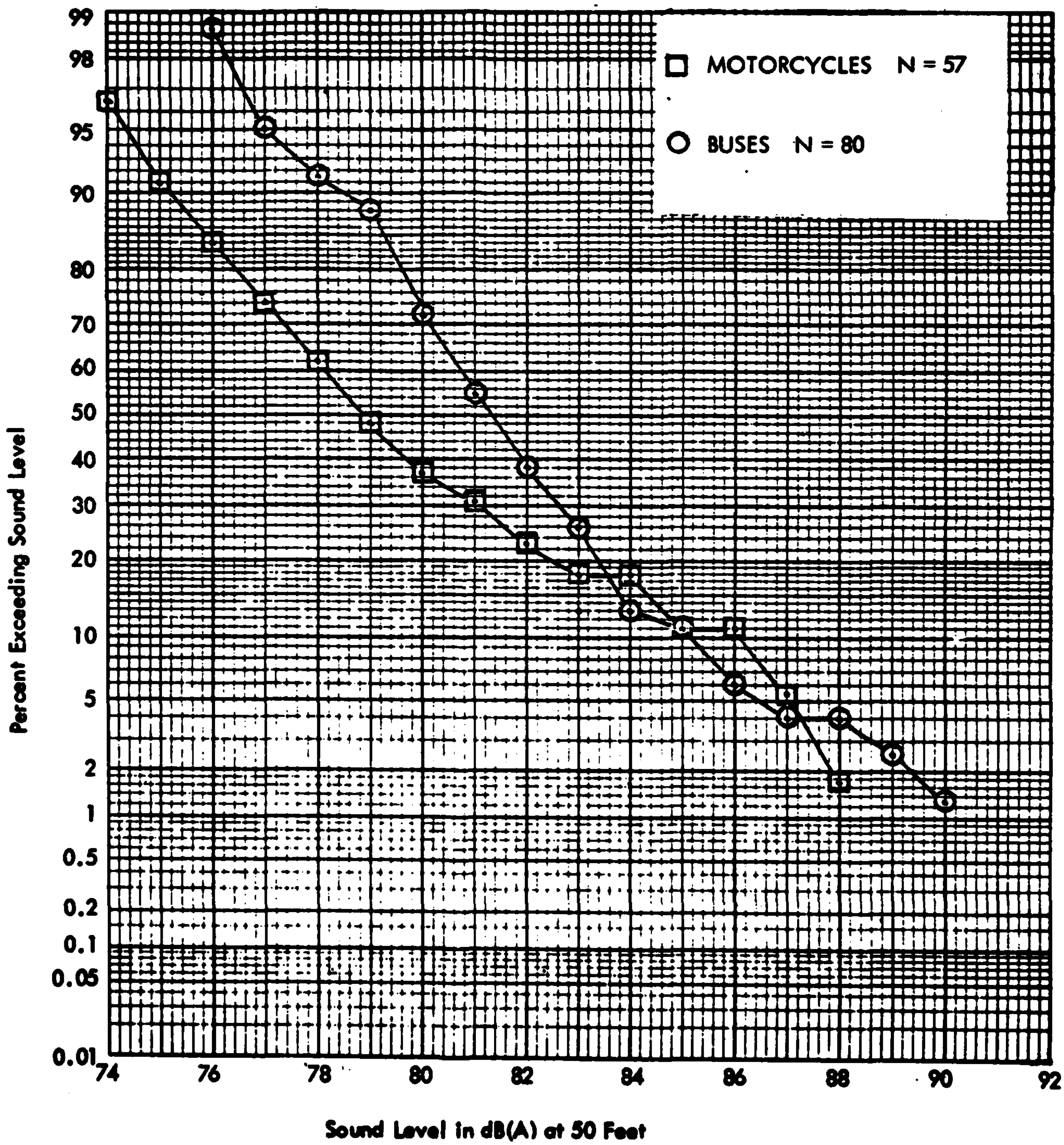


FIGURE E-4 STATISTICAL DISTRIBUTIONS FOR HEAVY TRUCK SOUND LEVELS WHILE ACCELERATING AND DURING LOW SPEED CRUISE ON CITY STREETS

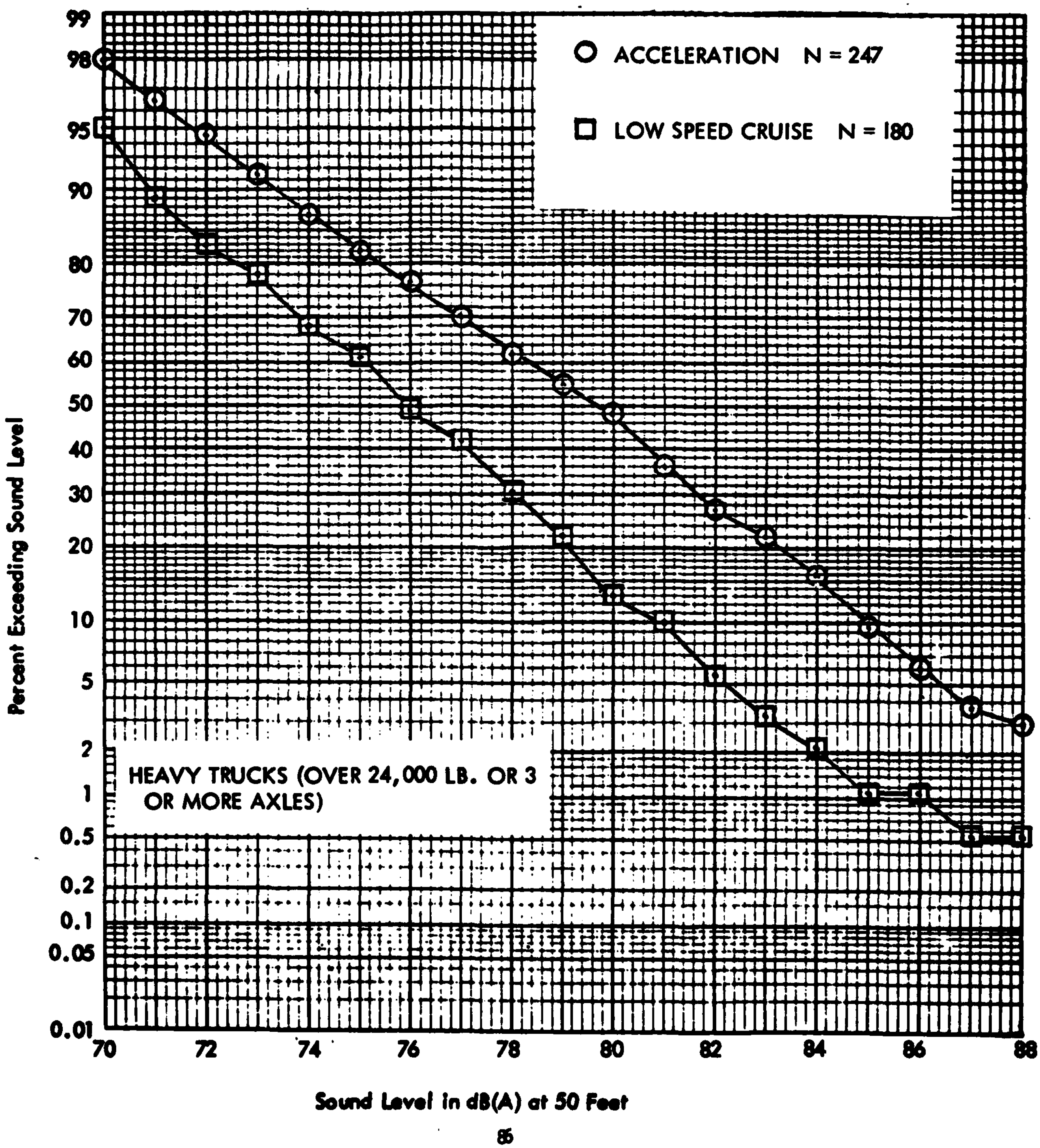
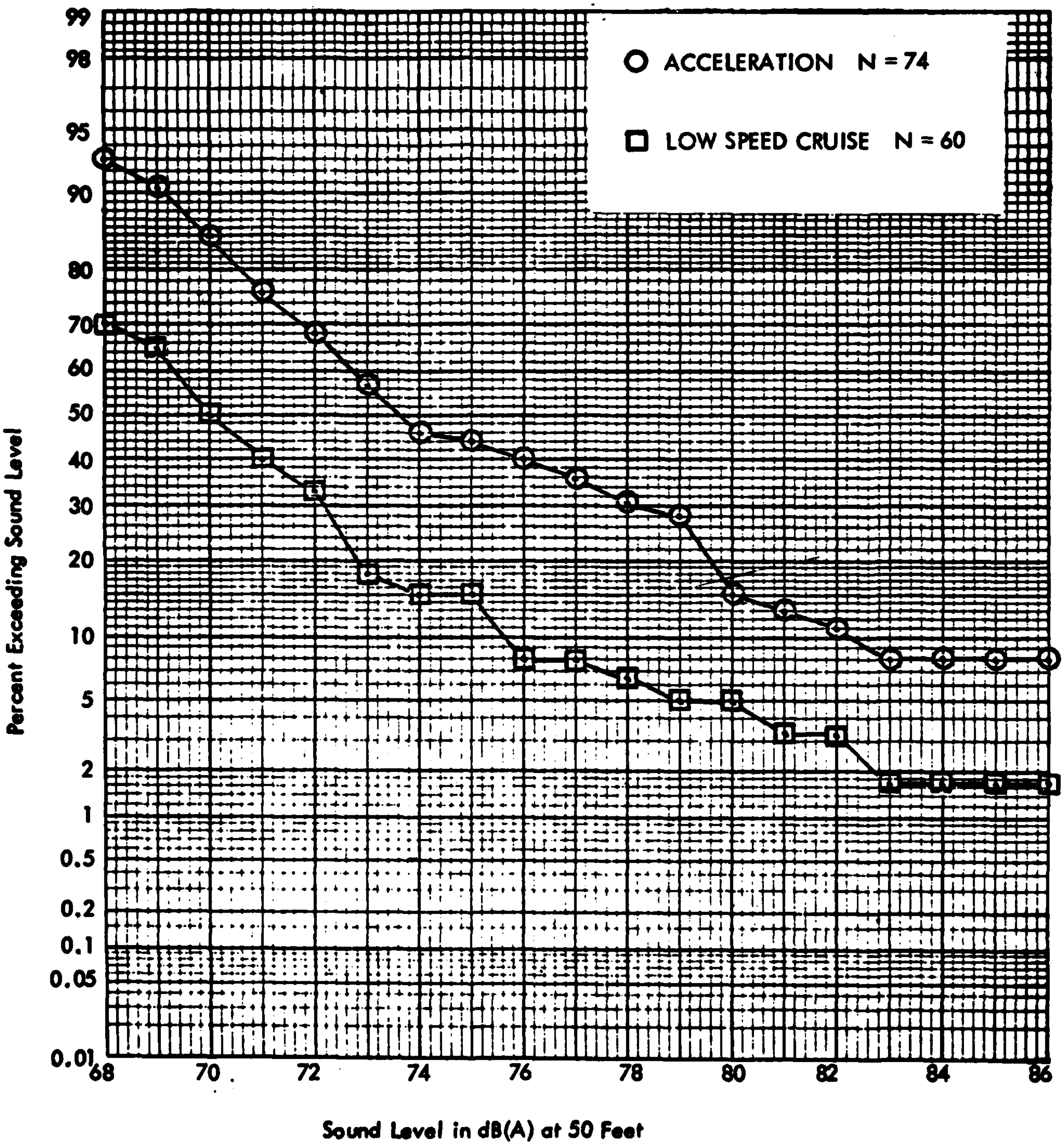


FIGURE E-5 STATISTICAL DISTRIBUTIONS OF MOTORCYCLE SOUND LEVELS WHILE ACCELERATING AND DURING LOW SPEED CRUISE ON CITY STREETS



Motorcycles are normally considered the most annoying source of noise on city streets in many neighborhoods. A comparison of Figures E-4 and E-5, however, shows that during acceleration 50 percent of the truck traffic causes 80dB(A) levels to be exceeded while only 15 percent of the accelerating motorcycles produce 80+dB(A) levels. During cruise 50 percent of the trucks exceed 76dB(A) levels while only 8 percent of the motorcycle traffic exceeds 76dB(A). These figures convincingly point out the truck as the most annoying source of noise on either the highway or the city street regardless of cruise or acceleration modes. In view of some of the other negative aspects of the heavy over-the-road truck, the present dependence and the trend toward increasing use of this mode of transportation needs to be examined in a most critical vein. In the context of noise pollution, at the very least, increased reliance on this mode of traffic at the expense of barge (or railroad) transportation would lead to a continuing deterioration of urban and rural environs.

F. The Mississippi Shore-Line

The height of various urban communities (from Alton upstream to St. Paul) above the Mississippi River is listed in Table F-1. The height of various communities situated along the Illinois River is enumerated in Table F-2. The lowest bluff-line height is at Burlington, Iowa (60 feet) while at Winona, Minnesota the bluff height reaches 560 feet above river level. The average bluff line height is approximately 271 feet above river level upstream from Alton, Illinois.

The manner in which noise reduction is calculated is shown in Table F-1 (also in Table 3 of Section II). The maximum (570 feet), average (271 feet), and minimum (60 feet) values listed in Table F-1 are used in Table A-2 for purposes of estimating the noise reduction effect the Mississippi River bluff line has on the propagation of sound intensity levels by river towboats and barge craft.

TABLE F-1

Mississippi Bluff Line - Alton to St. Paul

Location of Reading (by topographic quad.)	River Level (ft)	Bluff Level (ft)	Difference (ft)
Hastings, Minn. Wis.	680	840	160
Wabasha, Minn. Wis.	680	1140	460
Eau Claire, Minn. Wis.	680	1100	420
Winona, Wis. Minn.	640	1200	560
La Crosse, Wis.	640	1200	560
La Crosse, Wis.	640	1020	380
Potosi, Wis.	610	830	220
Guttenberg, Wis.	610	960	350
Bellevue, Iowa, Ill.	600	960	360
Green Island, Iowa, Ill.	590	800	210
Cordova, Ill. Iowa	590	670	80
Montpelier, Ill. Iowa	550	710	160
Blanchard Island, Ill. Iowa	530	700	170
Nauvoo, Iowa, Ill.	520	680	160
Burlington, Ill. Iowa	510	570	60
Warsaw, Ill. Mo.	480	610	130
Quincy, Ill. Mo.	460	710	250
Barry, Ill. Mo.	450	820	370
Hardin, Ill. Mo.	430	620	190
Brussels, Ill. Mo.	420	640	220
Alton, Ill. Mo.	420	640	220
		TOTAL ---	5690
		$\bar{X}$ = 271	

Merchant and Yantis use the following noise reduction (NR) formula to calculate decrease in sound level pressure from barriers:

$$NR = 10(\log N + 1)$$

when $N = \frac{2f}{C}\left\{R\left[\left(1 + \frac{H^2}{R^2}\right)^{\frac{1}{2}} - 1\right] + D\left[\left(1 + \frac{H^2}{D^2}\right)^{\frac{1}{2}} - 1\right]\right\}$

and f = frequency in Hz
R = distance to the barrier from the source
D = distance to the barrier from the receiver
C = velocity of sound in air

TABLE F-2

Illinois River Bluff Heights

Location of Reading (by topographic quad.)	River Level (ft)	Bluff Level (ft)	Difference (ft)
Brussels, Ill. Mo.	420	840	420
Hardin, Ill. Mo.	420	660	240
Beardstown, Ill.	440	580	140
Griggsville, Ill.	440	580	140
Manito, Ill.	440	580	140
Manito, Ill.	440	520	80
Peoria East, Ill.	450	630	180
Lacon, Ill.	460	640	180
Ottawa, Ill.	460	600	140
Morris, Ill.	485	525	40
		TOTAL ---	1700

$\bar{X} = 170$